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GROWTH PATTERNS AND DISTRIBUTION OF MAJOR TISSUES IN BEEF CATTLE

by

© HARI MOY MUKHOTY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Growth Patterns and Distribution of Major Tissues in Beef Cattle" submitted by Hari Moy Mukhoty, B.V.Sc. & A.H., M.Sc., in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

An investigation was undertaken to study the influence of breeds and sexes on the growth patterns and distribution of major tissues in beef cattle. Total dissection data were obtained from 63 bulls, 106 steers and 22 heifers representing 6, 8 and 2 breed groups respectively. Total and proportion of muscle, bone, fat and muscle:bone ratio differed significantly among breed groups of bulls and steers without showing any such difference between the two breeds of heifers.

Sex showed a marked influence on carcass composition with heifers fattening at lighter liveweights than steers and steers at lighter weights than bulls. Bulls showed a greater impetus for muscle growth followed by steers than heifers.

The relationships involving total muscle, muscle:bone ratio and percentage fat in the carcass were studied among divergent breed groups of bulls, steers or heifers and also among different sexes within a breed. Muscle plus bone was found a suitable common basis in breed and sex comparisons for adjusting total muscle in the carcass.

Muscle:bone ratio also showed satisfactory statistical relationship to compare the carcass merit of animals from different breeds and sexes at standardized weights. Percentage fat tended to increase in all breed groups of bulls, steers or heifers when various tissue weights, except bone, increased. In all sex comparisons at equal carcass weights, heifers had higher weights of fat than steers and steers were fatter than bulls.

Muscle weight distribution showed a significant breed variation in the abdominal and neck and thorax regions. There was no appreciable difference in the other anatomical locations of the

carcass. Heifers contained proportionately more muscles in the proximal hind and abdominal region compared with steers and steers compared with bulls. The trend of the sex influence was reversed in the muscles of neck and thorax. Growth coefficients further supported these findings.

The larger breeds contained proportionately more bone in the vertebral column and also in the long bones compared with the smaller breeds while the medium sized breeds were intermediate in positions. This trend of breed influences was completely reversed in the bones of ribs. Bulls contained proportionately more bones in all sections of the vertebral column, ribs, sternum and rib cartilages over steers and steers over heifers. This trend was found to be reverse in the long bones and in hip bones with heifers having greater proportions of these bones compared with steers and steers with bulls. The growth rate of bones in different sections relative to the total bone also showed similar trends.

The fatty tissue distribution was strongly influenced by different breed groups of bulls, steers or heifers. Beef breeds showed a trend of fattening from outside in and the dairy breeds from inside out. Estimates of growth coefficients of fatty tissues also were in line with these findings.

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TABLE OF CONTENTS

Page

Page

LIST OF TABLES

Table | Page

LIST OF FIGURES

INTRODUCTION

Since antiquity, man has attached importance to the source of his food supply. The domestication of food-producing animals brought a more dependable source of animal protein. Of course, man gradually learned to make use of domesticated animals for meat and eventually milk, wool and draft power.

The goal in meat animal production is to get a maximum of quality production from animals at a minimum expenditure. A yardstick is needed to accurately define quality and quantity of edible meat produced from a carcass of beef. The term quality has many different connotations, some very limited and precise and others all encompassing and general. In its broadest sense the term describes those attributes that supposedly contribute to the palatability of meat such as tenderness, flavour and juiciness. Quantity refers to the proportions of lean, fat and bone in the carcass. From the standpoint of the producer as well as the consumer, the most desirable carcass is one that contains only enough bone to give it a form, enough fat for eatability or to satisfy consumer and market conditions and contains a maximum proportion of lean meat. To achieve this goal a thorough understanding of the growth and developmental patterns of major tissues relating to carcass composition is necessary.

In the past a large amount of research effort has been directed towards the development of less accurate subjective visual appraisal techniques and simple objective measurements in beef cattle as estimates of carcass merit. More effective production of and selection for desired carcass composition could be practised if the growth

patterns of the major tissues were individually identified. This would also facilitate the possibility of control, by genetic and environmental means, thus influencing the production of animals to meet any specific requirements.

Attempts have been made in this research project to study the normal growth patterns of tissues in beef cattle and the genetic and sex influences which might affect these patterns. Another objective of this study was to investigate the feasibility of establishing the basis for comparing differences in the genetic merit of the carcass composition from divergent breed groups and between different sexes within a breed. This investigation was also directed to study the influence of breed and sex on the distribution of major tissues in the carcass especially in relation to the validity of time-honoured conviction that some breeds are superior in muscle weight distribution over the others, yielding more lean in high priced cuts.

REVIEW OF LITERATURE

I. Methods of studying growth and development in animals

Several statistical techniques have been developed for the examination of changes in carcass composition associated with changes in size, age and with differences between sexes and breeds, and between groups with different nutritional histories. Before discussing the different methods of analysis, a description of different kinds of primary data is essential. These may be divided into three main categories: static, cross-sectional and longitudinal and two further intermediate or mixed categories. This classification is essentially similar to those proposed by Kavanagh and Richards (1942), Tanner (1951) and Cock (1966). A description of the data categories follows.

(i) Static data: A group of individuals uniform with respect to age or liveweight is chosen, and the required set of measurements is made once and once only on each individual.

(ii) Cross-sectional data: As with static data, the set of measurements is made once only on each individual, but the entire group of individuals is divided into subgroups of different ages or liveweights. Cross-sectional data thus consists of a series of sets of static data on different sets of individuals. The accuracy of information on growth from cross-sectional data will increase with a corresponding reduction in the amount of variation within each subgroup, whether of genetic or environmental origin.

(iii) Longitudinal data: In this category a complete record of growth from a series of sets of measurements at each of a series of

predetermined ages or liveweights are obtained for each individual. These are the ideal kind of data, although practical difficulties often make their realization impossible.

(iv) Mixed cross-sectional data: In true cross-sectional data, it is essential that the division into subgroups be on the basis of known ages or liveweights. Frequently, however, data have been collected on animals which are known to be uniform in age or liveweight but in which no independent criterion of age or liveweight is available. Such data will be referred to as mixed cross-sectional data.

(v) Mixed longitudinal data: These are longitudinal data in which the record of some individuals are incomplete, that is, do not extend over the full range of ages being studied. Thus they combine certain features of the longitudinal and cross-sectional categories.

Once having obtained the data several different approaches to expressing changes in development have been used (Butterfield,1963; Tulloh,1963). Both bivariate and multivariate procedures are possible. In the simple cases of analyses where one criterion of growth and development is involved, the five commonly used methods are as follows:

(i) Liveweights or the weights of organs and tissues of animals expressed against ages at definite intervals.

(ii) The weight of the part (or organ or tissue) expressed as a percentage of body weight at various body weights or ages.

(iii) The weight of part expressed as a fraction of body weight at one age (or weight), compared with the fraction calculated at

another age (or weight). One of the ages is usually at birth.

(iv) The measurement of the part expressed as a percentage of its measurement at an earlier age or weight (usually at birth).

(v) The part expressed by a measurement in any one of the above three (ii, iii, iv) ways, in relation to a measurement of a standard part (other than liveweight), which is usually called control dimension. The control dimension or part which is chosen is one which shows relatively little change throughout postnatal life. The liveweight of the animal should not be used as a control dimension in carcass composition studies. The contents of the alimentary tract and other viscera, which have a strong circadian variation, influences liveweight strongly. However, shrunk body weight (liveweight after 16-24 hrs. of fasting) might reduce this variation but again it involves serious interruptions with the normal growth process. Empty body weight or half carcass weight is preferable to liveweights because it is free from such variability. The major objection of carcass weight has been the proposition that fat tissue is a product of animal nutrition rather than animal growth (Maynard, 1947; Elsley et al., 1964) and therefore it has been suggested that all comparisons should be made on either fat-free or fat-corrected basis (Everitt, 1966). However, bone or muscle plus bone has been used by Berg and Butterfield (1966) as control dimensions after checking the legitimacy of using these fat-free bases by one-way analyses of covariance.

The mathematical and statistical operations that could be used depend on the nature of the data. With longitudinal data several models have been developed to describe the growth process. The most commonly used functions that have been used are logistic, Gompertz,

von Bertalanffy and Richard's generalised curve functions (Brody, 1945; von Bertalanffy, 1957; Laird, 1965; Cartwright, 1970; Eisen, et al., 1969). Orthogonal polynomials have also been fitted to describe growth in one variable analysis of longitudinal data (Kidwell and Howard, 1970). This procedure needs equally spaced measurements on X and Y. However, when X's are not equally spaced, polynomials must be specially constructed (Wishart and Metakides, 1953). Some of these functions have been used on the basis of assumptions about the growth process and others empirically. None has yet been universally accepted as best. Best used in this context usually denotes the goodness of fit criterion of minimum error variance for the fitted curve. All of these curves either underestimate or overestimate some parts of the normal growth curve. The average growth rate (of organs or tissues) expressed against unit time is not subject to very great objection providing that the interval of time is short. If the interval of time is long the average growth rate is a poor indicator of the growth rate at any particular time. However, with cross-sectional data, one-way analyses of variance has been extensively used to test treatment or group differences. To bring out more specific information of treatments, tests comparing multiple means could also be used.

Statistical techniques based on the theory of least squares have also been used. Nevertheless, assumptions have to be made for their use. Thus in the application of least squares techniques to fitting the curve $Y = ax^b$ ($\log Y = \log a + b \log X$) it is assumed that error occurs only in the criterion scored, Y. If both X and Y are weights of parts of animal, there is no real justification for this

assumption. Haldane (1950) described an alternative technique of estimating the allometric coefficient "b" allowing errors in both X and Y. Reeve (1950) showed that with a particular set of data there is little variation between this technique and the normal regression technique, as far as the differences between "b" on different groups of animals are concerned. If allowances for errors in both X and Y are made when comparing groups of animals, the differences between slopes for each treatment will not be altered to any extent unless variation about the regression lines differs markedly between groups. In one-way analyses of covariance (without allowance for error in X) the difference between treatments in variation about the regression lines could be tested and, therefore, discovered. If the "b" values are found to be homogeneous among treatment groups, the adjusted means should be estimated through the pooled "b" value (Winer, 1962). The adjusted means between treatments could also then be tested for significant differences (Bancroft, 1968). If the "b" values are found to be non-homogeneous between treatment groups, the adjusted means should not be estimated using pooled "b", rather each treatment "b" should be used. In the latter case, the adjusted means cannot be tested for significant differences (Williams, 1959).

Additionally, the positions of the slopes between treatments could also be tested for significant differences. Basically, the test of significant differences between intercepts is in fact a test of means adjusted for the independent variables (Williams, 1959).

Multivariate procedures where more than one independent variable is used, can be considered as extensions of the bivariate case. Multiple regression techniques have been found to be quite useful and

revealing. For example, in an investigation of the effects of breed and sex on the development of carcass composition of lambs, Seebeck (1966) by using age (log) as an independent variable as well as carcass weight, found that age did not reduce the residual standard error of Y more than 5 to 10% over and above what was already explained by carcass weight. The problem of this technique, when a larger number of independent variables are chosen, lies in selecting the best regression equation with an intention of using as few X's as possible and developing maximum reliability of the equation for predictive purpose or to study the response in the criterion scored (Y). There is no unique statistical procedure for doing this. Personal judgement should be used in most of the cases. However, the general principle is to set up first the "all possible regressions" and then to try "backward elimination" or "forward selection or stepwise regression techniques" to reach the desired equation (Draper and Smith, 1966). However, the importance of each of the independent variables could be estimated through standardised partial regression coefficients. Additionally, the feasibility of applying a multiple regression equation on one group which has been developed in another group over the same sets of variables could be checked by cross validation techniques.

Alternative multivariate procedures are the direct extension of one-way analysis of covariance. This appears to be a worthwhile test in cases such as that described by Boccard et al. (1964) who found that muscle weight, but not bone or fat, was significantly affected by treatment applied.

A further procedure which involves the study of response in one

variable due to several levels of other different variables is called response surface technique (Box, 1952). Only recently has it been used in animal experimentation (Chandler *et al.*, 1967).

II. Methods of studying tissue distribution

The classical studies on tissue distribution in animals were made by McMeekan in swine (1940), Palsson in sheep (1940) and Callow in cattle (1944). Even before these studies, Wilson and Curtis (1893) in Iowa and Moulton *et al.* (1922, 1923) in Missouri did extensive studies on the effects of different nutritional regimes on the tissue distribution in cattle. Recently, a number of workers (Butterfield, 1963; Robertson *et al.*, 1967; Harte, 1968; Seebeck, 1968) have been interested in the effects of breed and sex on tissue distribution.

Two anatomical approaches have been made to study the distribution of major tissues in beef cattle, namely: (a) semi-anatomical (Pomeroy, 1960) and (b) anatomical method (Butterfield, 1963).

The first method involves the physical separation of the commercial retail cuts from a whole carcass or a side of a carcass into its component tissues of muscle, bone or fat (Robertson *et al.*, 1967; Harte, 1968; Seebeck, 1968). The weights of the major tissues in each joint are then expressed as percentages of the total tissue weights in the carcass. Statistical techniques are then applied on those percentage means to test the significant differences arising from breed, sex or nutritional treatments. Very commonly, one-way analysis of variance along with any standard procedures of multiple mean comparison were used. However, if the variation in weight and age of the animals used in different treatment groups were not standardised, these two

sources of variation might be confounded and not separable by statistical techniques. In the latter case, one-way analysis of covariance would be the legitimate statistical technique using the percentages of tissues in each joint as the criterion scored (Y) and the corresponding total tissues in the carcass as a covariate (X). If the age or weight of the animals between treatments are not uniformly constant and spread over a long range of liveweights, logarithmic transformation of both the variables would be necessary. Again, if the animals are of uniform age or liveweights, the criterion scored (Y) could be the total tissue in each joint (not the percentage of total tissue) and X be the total tissue in the carcass. When analysis is done by covariance techniques, the homogeneity of slopes between treatments should be checked before estimating the adjusted means. If the "b's" are found to be homogeneous, the adjusted means could be estimated through the pooled "b"; otherwise treatment "b's" should be used to estimate the adjusted means.

There are certain advantages for a semi-anatomical technique. This method is comparatively easy as it does not require detailed anatomical knowledge, but it is not universal because within narrow ranges of modifications, the demarcations of retail cuts differ from country to country (Pomeroy, 1960; Yeates, 1965). The reproducability of the retail cuts based upon standardised butchering practice is poor compared to the method of jointing meat carcasses based upon their anatomical structure (William, 1968). Another demerit of the retail cut system is that some high-valued muscles (e.g. longissimus dorsi muscle in the loin region) are lumped with low-valued muscles (e.g. rectus, obliquus and transverse abdominis muscles) as pointed out by

Pomeroy (1960). Sometimes one muscle is split up into different cuts (e.g. longissimus dorsi into 'rump', 'loin and wing end' and 'fore rib') resulting in appreciable changes in the corresponding cuts in response to a physiological change in one muscle.

The anatomical procedure involves the separation of the carcass into its component tissues maintaining their anatomical entity. The distribution of individual bones and component fatty tissues (sub-cutaneous, intermuscular and internal) could then be studied exactly in the same way as discussed earlier. Muscle weight distribution can be studied for each individual muscle or anatomical group of muscles (Butterfield, 1963). This grouping of muscles is not open to very great objection provided it is done maintaining their anatomical entity. A group of muscles in a particular part of the body become specialised according to the functional demands imposed on them from birth to a certain stage of development. This may, in part, lead to the origin, insertion and adherence of one or a group of muscles completely distinguishing them from other muscles in the body.

EXPERIMENTAL

I. Objectives

The purpose of the present investigation was to study the growth and developmental patterns of major tissues in beef cattle.

Research has been directed toward four major objectives, namely to study the influence of breed and sex groups on:

(A) growth and relationships among major tissue components of the beef carcass,

(B) muscle weight distribution and growth patterns of anatomical muscle groups,

(C) bone weight distribution and growth patterns of bone components, and

(D) fatty tissue distribution and growth patterns of the major fat components.

II. Materials and Methods

A. Experimental animals

One hundred and ninety-one cattle consisting of 63 bulls, 106 steers and 22 heifers representing 6, 8 and 2 breed groups respectively were used in this experiment. Most of these animals were from the University of Alberta beef research herd at Kinsella, Alberta. The breeding plan and general management of the project has been outlined in detail by Berg and McElroy (1968). Calves were born in April and May, nursed on their mothers without creep feed until October when they were weaned. They were then transferred to a performance test ration of concentrates and cut hay. The concentrate was full fed and consisted of a grain mixture of rolled oats and barley in 1:3 ratio by

weight plus a protein-mineral-vitamin supplement at a level of 5% of the grain mixture.

Holstein and Jersey bull calves were taken from the dairy cattle research herd of the University of Alberta. Hereford steers and heifers were from a commercial progeny test program in Alberta. These animals were raised under similar conditions to those at Kinsella and were fed high energy rations ad libitum for a minimum period of 140 days prior to slaughter.

Breed groups represented purebred and crossbred beef and dairy breeds. A synthetic line, referred to as "Hybrid", was a combination of Charolais, Angus and Galloway breeds (Berg and McElroy, 1968). In all cases where crossbreds were involved the breed of sire is listed first and the breed of dam following. When a cross involved one sire breed and several dam breeds, only the sire breed is listed e.g., Shorthorn cross and Brown Swiss cross.

Two principles were followed in allotting animals for slaughter. The first was an attempt to sample each group of animals serially extending well above and below the normal market weight for the class and the second was to attempt to get valid group (sex and breed) comparisons for animals treated alike. Limits imposed by the dissection procedure caused deviations from the plan. To meet the objectives of the present study, it was considered more important to obtain a sampling of each group over a range in liveweights than to achieve equality in mean slaughter weights.

B. Total dissection technique

The animals used in this experiment were slaughtered at a

commercial packing plant following routine procedures. The carcass comprised the eviscerated body with the removal of the head at the atlanto-occipital articulation, the thoracic limbs at the carpo-metacarpal articulation, the pelvic limbs at the tarso-metatarsal articulation and the tail at the first intercoccygeal articulation. The skin was removed with a few bands of cutaneous trunci and cutaneous omobrachialis muscle from the dorsal region adhering. Half carcasses were removed to the University Meats Laboratory where separation into muscle, bone and fat was done by the total anatomical dissection technique of Butterfield and May (1965).

The author also modified this technique when it was found convenient from his own experience. The principle followed was that fat and other tissues contain no muscle but muscle contains some other tissues. Therefore severence of muscle from tendon was made at the level of the last vestige of muscle. The weights of one hundred individual muscles were recorded. Certain muscles were not weighed and became scrap e.g., muscles of the tail (sacrococcygeus dorsalis, lateralis and ventralis) and diaphragm (tendinous center with muscular costal and sternal parts). The weights of fourteen components of bone freed from fat and tendons were also recorded. Fatty tissue was weighed in three categories: subcutaneous, intermuscular and internal (body cavity) fat. Tendons were weighed separately. The approximate temperature and relative humidity of the meat dissection laboratory was 60-65°F and 50-55% respectively. This prevented the loss of moisture from the muscle during dissection. Other precautions taken during the dissection of the carcass and the merits and demerits of this technique have been discussed elsewhere (Mukhoty, 1969).

C. Statistical analyses

The principles of computational procedures were adapted from Bancroft (1968), Steel and Torrie (1960) and Williams (1959). The APL system in the IBM 360/67 computer through an IBM 2741 terminal was used. In addition, several other programmes written by the author in Fortran IV programming language were used. Specific statistical procedures are outlined in the relevant sections of the thesis.

III. Results and Discussions

(A) Growth and relationships among major tissue components of the beef carcass

(1) Breed influence on total, proportion of muscle, bone, fat and muscle:bone and muscle:fat ratios

Age and liveweights at slaughter along with means and standard deviations of cold carcass weights, total and proportion of muscle, bone, fat and muscle:bone and muscle:fat ratios from diverse genetic groups of bulls, steers and heifers are shown in Table 1. Breed groups of bulls and of steers differed significantly ($P < 0.01$) in all of these traits. These differences are largely a reflection of the slaughter plan followed and the great diversity in optimum slaughter weight among the diverse genotypes studied. The two breed groups of heifers were quite similar in mean ages, liveweights, cold carcass tissue weights reflecting a similarity in their tissue growth and developmental patterns.

(2) Breed influence on regression coefficients and adjusted means from the relationships involving total muscle, muscle:bone ratio and percentage fat as independent variables

One of the major objectives of this part of the present investigation was to extract information on the relative growth and develop-

TABLE 1

Means and pooled standard deviations of age, live weight, cold carcass weight and component tissues from the dissection data of half carcasses of different breed groups of bulls, steers and heifers

Sex	Breed	Number of Animals	Age days	Live Weight kg	1/2 cold carcass weight kg	Muscle kg	Muscle %	Bone kg	Bone %	Fat kg	Fat %	Muscle: bone ratio	Muscle: fat ratio
Bulls	Hereford	13	461 (329-544)[1]	466.2 (349-562)	135.3	80.4	60.6	15.3	11.6	37.4	27.3	5.3	2.3
	Hybrid[2]	17	443 (329-514)	496.5 (363-603)	145.4	95.7	66.4	17.3	12.1	30.2	21.0	5.5	3.3
	Hybrid X Hereford	5	388 (346-427)	470.3 (372-572)	135.9	80.9	60.6	16.9	12.7	35.9	26.1	4.8	2.4
	Shorthorn Cross	12	361 (252-486)	386.1 (245-535)	107.8	73.1	64.9	13.9	13.8	23.8	21.1	5.1	3.3
	Holstein	8	386 (364-402)	416.0 (394-472)	111.1	75.9	69.2	18.3	16.7	14.9	13.5	4.2	5.2
	Jersey	8	407 (389-448)	294.0 (267-358)	73.8	47.0	65.3	10.7	14.9	14.0	19.2	4.4	3.7
	Pooled standard deviations:		57.6	72.4	24.3	14.4	3.6	2.0	1.2	9.1	4.2	0.5	0.8
	Variance ratios:		5.3**	10.4**	11.9**	13.0**	7.9**	16.8**	24.9**	11.1**	12.8**	13.5**	14.3**
Steers	Hereford	11	402 (367-499)	373.9 (340-440)	107.4	61.7	58.1	12.7	12.0	31.8	29.5	4.9	2.0
	Hybrid	16	433 (300-505)	461.5 (345-567)	133.4	73.6	56.1	15.7	12.0	42.0	31.4	4.7	1.9
	Hereford X Hybrid	8	441 (404-483)	433.6 (367-451)	120.2	72.5	60.7	15.5	13.0	31.1	25.8	4.7	2.4
	Hybrid X Hereford	16	434 (382-482)	461.8 (408-540)	131.7	74.1	56.8	15.5	11.9	40.4	30.8	4.8	2.0
	Hereford X (A.G.)[3]	13	425 (322-456	439.2 (354-490)	124.5	70.2	57.0	14.4	11.8	38.4	30.7	4.9	1.9
	Shorthorn cross	22	383 (290-509)	376.9 (245-518)	97.2	61.8	58.9	12.8	13.1	30.6	28.4	4.8	2.1
	Brown Swiss cross	14	404 (313-489)	456.8 (363-522)	126.0	75.8	60.8	17.3	13.9	30.9	24.6	4.4	2.5
	Holstein	6	480 (369-558)	466.9 (394-503)	127.7	75.5	59.9	18.2	14.5	31.8	25.0	4.2	2.4
	Pooled standard deviations:		54.7	57.5	23.9	9.6	3.6	1.8	1.2	9.0	4.4	0.3	0.5
	Variance ratios:		3.3**	6.4**	4.9**	5.2**	3.3**	14.6**	7.6	4.1**	4.7**	5.5**	3.9**

continued

TABLE 1 (continued)

Means and pooled standard deviations of age, live weight, cold carcass weight and component tissues from the dissection data of half carcasses of different breed groups of bulls, steers and heifers

Sex	Breed	Number of Animals	Age days	Live Weight kg	1/2 cold carcass weight kg	Muscle		Bone		Fat		Muscle: bone ratio	Muscle: fat ratio
						kg	%	kg	%	kg	%		
Heifers	Hereford	10	365 (359-369)	305.5 (276-349)	85.7	49.2	57.6	10.1	11.8	25.9	30.4	4.9	1.9
	Shorthorn cross	12	398 (310-500)	345.8 (241-463)	98.2	53.9	57.1	11.0	12.5	31.1	31.2	4.9	1.9
Pooled standard deviations:			44.5	61.4	20.2	9.4	2.6	1.7	1.3	8.8	3.6	0.4	0.3
Variance ratios:			3.1	2.3	2.1	1.4	0.2	1.5	1.5	1.9	0.3	0.1	0.1

** Significant at ($P < 0.01$).
1 Numbers indicate range values.
2 Hybrid refers to a synthetic line developed from Charolais, Angus and Galloway breeds.
3 (A.G.) signifies Angus X Galloway.

mental patterns of major tissues in beef cattle. To achieve this goal, breed and sex group differences were appraised on total muscle, muscle:bone ratio and percentage fat when adjusted to common size dimensions by one-way analysis of covariance holding several other variables constant e.g. muscle, bone, fat, muscle plus bone and cold carcass weight.

Total muscle was chosen because it is the major and most valuable tissue in the carcass. Muscle:bone ratio was preferred to bone because this ratio serves the function of an index for assessing muscle and bone development in one figure. Moreover, this ratio becomes critical to the value of the carcass as muscle is the most valuable tissue in the carcass and bone is the least valuable. Furthermore, this ratio, being independent of fat, is comparatively less influenced by environment and is perhaps a better determinant of genetic merit of a carcass for any particular breed. Percentage fat was chosen because excess of fatty tissue is of low economic value. Its level in the carcass can be readily controlled by environmental means (Mukhoty et al., 1970) and so its inclusion will thwart the precision of comparisons involving muscle and bone. Moreover the undesired fat is a tremendous waste of consumed energy.

Another objective was to explore the feasibility of establishing a basis for comparison of carcass composition of divergent breed groups and of beef cattle from various treatments with the clear understanding of the relationships involving total muscle, muscle:bone ratio and percentage fat.

Relationships involving total muscle

In Tables 2, 3 and 4 are shown regression coefficients (b) and

TABLE 2

Adjusted means ($\overline{y}'$) and regression coefficients (b) with total muscle weight, muscle:bone ratio and percentage fat as dependent variable based on the half carcass dissection data from sixty-three bulls of six different breeds

Dependent Variables		Total Muscle Weight				Muscle:Bone Ratio					Percentage Fat				
Independent Variables		Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight
Breed															
Hereford	b	5.17	0.55	0.87	0.79	0.02	0.011	0.012	0.014	0.005	0.26	1.18	0.42	0.18	0.20
	$\overline{y}'$	81.56	70.61	77.90[c]	73.47	5.19[a]	5.28	5.12[a]	5.20[a]	5.11[a]	27.24	27.41[a]	23.28	27.24[a]	26.36
Hybrid	b	6.65	0.94	0.91	0.71	0.03	0.087	0.003	0.024	0.016	0.08	0.27	0.38	0.05	0.01
	$\overline{y}'$	84.83	92.70	77.67[c]	83.56	5.07[a]	5.40	5.49[a]	5.09[a]	5.27[a]	22.22	20.31[e]	19.74	21.69[e]	19.29
Hybrid X Hereford	b	4.68	0.64	0.88	0.41	0.02	0.001	0.001	0.018	0.005	0.30	2.56	0.37	0.29	0.12
	$\overline{y}'$	72.44	72.52	76.53[d]	73.65	4.71[c]	4.69	4.68[c]	4.69[c]	4.64[c]	25.98	25.35[c]	22.63	25.95[c]	25.08
Shorthorn cross	b	6.47	1.77	0.89	0.46	0.021	0.121	0.041	0.018	0.012	0.10	0.72	0.24	0.08	0.05
	$\overline{y}'$	82.72	75.92	78.12[a]	80.31	5.23[a]	5.19	5.11[a]	5.23[a]	5.23[a]	21.35	21.94[e]	22.31	21.36[e]	22.13
Holstein	b	2.48	1.29	0.77	0.57	0.03	0.890	0.041	0.008	0.021	0.09	0.06	0.58	0.06	0.08
	$\overline{y}'$	59.06	87.17	74.74[e]	81.47	4.20[e]	3.95	4.32[c]	4.14[e]	4.29[c]	13.63	12.05[d]	18.16	13.48[d]	14.29
Jersey	b	5.93	0.25	0.88	0.51	0.04	0.147	0.018	0.034	0.023	0.01	-0.17	0.97	0.11	0.28
	$\overline{y}'$	75.95	59.06	78.36[a]	72.24	5.12[a]	4.77	4.58[c]	5.11[a]	4.96[a]	20.59	21.71[e]	24.19	20.26[e]	22.73
Variance ratio: Between slopes[1]		5.67**	4.81**	1.27	4.21**	0.56	4.45**	1.03	0.66	0.94	3.55**	1.83	3.74**	2.15	3.62**
Between intercepts		----	----	18.01**	----	14.49**	----	8.03**	14.62**	9.25**	----	11.82**	----	3.57**	----

** Significant at ($P < 0.01$).

---- Missing values indicate analyses of covariance and comparisons of adjusted means not legitimate.

1 5 and 51 degrees of freedom.

a c d e means having different superscript in a column differ significantly at ($P < 0.01$ or $P < 0.05$).

$\overline{y}'$ indicates independent variable adjusted to overall mean of X(muscle = 78.37 kg; bone = 15.45 kg; fat = 26.92 kg; muscle plus bone = 92.87 kg; cold carcass wt. = 121.85 kg).

TABLE 3

Adjusted means ($\overline{y}'$) and regression coefficients (b) with total muscle weight, muscle:bone ratio and percentage fat as dependent variable based on the dissection data from one-hundred and six steers of eight different breeds

Dependent Variables		Total Muscle Weight				Muscle:Bone Ratio					Percentage Fat				
Independent Variables		Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight
Breed															
Hereford	b	4.22	0.68	0.85	0.41	0.01	0.020	0.011	0.011	0.002	0.28	1.55	0.57	0.25	0.23
	$\overline{y}'$	72.12	63.53	70.64^{a}	65.63	5.04^{a}	4.90	4.92^{a}	5.03^{a}	4.95^{a}	29.83	29.44	30.91	29.81^{a}	30.47
Hybrid	b	3.10	0.37	0.84	0.39	0.01	0.096	0.008	0.006	0.005	0.09	0.32	0.43	0.09	0.19
	$\overline{y}'$	69.93	69.58	69.73^{c}	69.04	4.63^{a}	4.69	4.71^{a}	4.64^{a}	4.62^{a}	31.28	31.45^{a}	28.47	31.30^{a}	30.34
Hereford X Hybrid	b	1.70	0.56	0.82	0.47	0.03	-0.16	0.038	0.004	0.012	0.28	-0.45	0.59	0.17	0.24
	$\overline{y}'$	69.98	74.69	69.78^{c}	72.23	4.67^{a}	4.71	4.77^{a}	4.77^{a}	4.71^{a}	25.68	25.79^{c}	27.43	25.69^{c}	25.72
Hybrid X Hereford	b	4.65	0.23	0.85	0.41	0.01	0.004	0.005	0.009	0.002	0.45	1.95	0.57	0.38	0.18
	$\overline{y}'$	71.37	71.00	69.97^{c}	70.12	4.70^{a}	4.78	4.71^{a}	4.71^{a}	4.70^{a}	30.68	30.86^{a}	28.54	30.70^{a}	29.89
Hereford X (A.G.)	b	2.56	0.13	0.93	0.27	0.05	-0.17	0.008	0.041	0.013	0.03	-1.17	0.54	0.01	0.35
	$\overline{y}'$	72.50	68.27	70.35^{a}	68.56	4.86^{a}	4.88	4.83^{a}	4.87^{a}	4.84^{a}	30.72	30.71^{a}	29.32	30.74^{a}	30.34
Shorthorn cross	b	6.06	1.34	0.86	0.44	0.021	0.112	0.031	0.018	0.008	0.13	0.75	0.26	0.11	0.07
	$\overline{y}'$	71.88	64.33	70.59^{a}	69.10	4.97^{a}	4.84	4.87	4.96^{a}	4.95^{a}	28.70	28.27^{a}	30.27	28.63^{a}	30.15
Brown Swiss cross	b	4.41	0.85	0.85	0.57	0.02	0.010	0.012	0.012	0.008	0.01	0.04	0.40	0.01	0.06
	$\overline{y}'$	64.76	78.15	68.68^{d}	73.70	4.27^{c}	4.36	4.44^{c}	4.26^{c}	4.35^{c}	24.42	24.73^{c}	26.38	24.42^{c}	24.14
Holstein	b	1.44	0.25	0.93	0.30	0.02	0.141	0.032	0.022	0.012	0.08	0.10	0.27	0.08	0.07
	$\overline{y}'$	60.38	77.38	67.89^{e}	72.83	4.04^{c}	4.11	4.19^{c}	4.02^{c}	4.09^{c}	24.75	25.09^{c}	26.35	24.72^{c}	24.32
Variance ratio: Between slopes[1]		4.70**	9.15**	0.956	2.81**	0.77	4.59**	1.06	0.96	0.41	2.81**	1.88	5.77**	2.03	2.89**
Between intercepts		----	----	11.48**	----	12.91**	----	5.92**	11.26**	9.15**	----	4.24**	----	3.01**	----

** Significant at ($P < 0.01$).

---- Missing values mean analyses of covariance and comparisons of adjusted means not legitimate.

1 7 and 90 degrees of freedom.

a c d e f means having different superscript in a column differ significantly at ($P < 0.01$ or $P < 0.05$).

$\overline{y}'$ indicates independent variable adjusted to overall mean of X(muscle = 69.88 kg; bone = 14.92 kg; fat = 35.03 kg; muscle plus bone = 84.79 kg; cold carcass wt. = 119.54 kg).

TABLE 4

Adjusted means ($\overline{y}'$) and regression coefficients (b) with total muscle weight, muscle:bone ratio and percentage fat as dependent variable based on the dissection data from twenty-two heifers of two different breeds

Dependent Variables		Total Muscle Weight				Muscle:Bone Ratio					Percentage Fat				
Independent Variables		Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight
Breed															
Hereford	b	4.12	0.73	0.84	0.34	0.02	0.040	0.040	0.010	0.011	0.31	1.65	0.60	0.27	0.29
	$\overline{y}'$	51.57	51.92	51.80	52.21	4.95	4.90	4.96	4.94	4.95	31.03	30.87	31.41	31.02	31.30
Shorthorn cross	b	5.01	0.98	0.85	0.43	0.019	0.101	0.022	0.015	0.006	0.32	0.91	0.35	0.27	0.15
	$\overline{y}'$	51.93	51.63	50.73	51.39	4.78	4.91	4.76	4.78	4.77	30.69	30.82	30.37	30.69	30.46
Variance ratio: Between slopes[1]		4.55*	6.02*	0.08	9.27**	0.02	4.57*	0.08	0.03	0.09	8.47**	1.66	9.56**	1.88	16.20**
Between intercepts		----	----	4.50*	----	5.62*	----	5.03*	4.98*	5.32*	----	4.56*	----	4.51*	-----

* Significant at ($P < 0.05$).

** Significant at ($P < 0.01$).

---- Missing values indicate analyses of covariance and comparisons of adjusted means not legitimate.

1 1 and 18 degrees of freedom.

$\overline{y}'$ indicates independent variable adjusted to overall mean of X(muscle = 51.76 kg; bone = 10.55 kg; fat = 28.69 kg; muscle plus bone = 62.37 kg; cold carcass wt. = 92.47 kg).

adjusted means ($\bar{y}'$) from the relationships involving total muscle with bone, fat, muscle plus bone and cold carcass weights from different breeds of bulls, steers and heifers.

In all breed groups of bulls, steers and heifers the slopes were found to be non-homogeneous when the relationships between total muscle and bone, fat and cold carcass weights were studied. This would indicate that when bone, fat and cold carcass weights were held constant in bulls, steers or heifers, the rates of muscle formation were significantly ($P<0.01$ or $P<0.05$) different among divergent breeds of the respective sex groups. Breed differences in the adjusted means of muscles could not be tested from the above mentioned relationships because of the heterogeneous nature of the slopes.

However, at a constant level of muscle plus bone in the carcass, various breed groups of bulls, steers or heifers followed a similar pattern in the rates of lean tissue growth as indicated by the homogeneity of slopes. In this case, tests to check the breed differences in adjusted means of muscle were legitimate and so were done. Among different breeds of bulls, Jersey (JR) and Shorthorn cross (SH) had significantly ($P<0.01$ or $P<0.05$) higher amounts of lean and Holstein (HL) had the lowest amount of lean in the carcass. Hybrid (HY), Hereford (HE) and HY X HE were intermediate in position.

In steer groups, HE, HE X (A.G.) and SH contained more lean at a constant level of muscle plus bone and this in turn was followed by HY, HY X HE and HE X HY groups. Dairy breeds e.g., Brown Swiss cross (BS) and HL contained less muscle compared to the other breed groups of steers. Between two breeds of heifers, HE had significantly ($P<0.05$) more lean than SH when adjusted to a common level of muscle

plus bone.

In predicting total muscle tissue in the carcass, muscle plus bone was found to be a legitimate covariate in all breeds of three sex groups. Additionally, there were significant breed differences in total muscle when adjusted to a common level of muscle plus bone. Selection on the basis of this test criterion could be designed to emphasize higher lean content in the carcass although it may be difficult in practice.

Relationships involving muscle:bone ratio

Tables 2, 3 and 4 also relate muscle:bone ratio to muscle, bone, fat, muscle plus bone and cold carcass weight in bulls, steers, and heifers respectively. In general, the rate of increase in muscle:bone ratio as all other independent variables, except bone, increased was comparatively very small over the range of these data. This is indicated by low positive regression coefficients.

The regression of muscle:bone ratio on bone was heterogeneous among different breed groups of bulls, steers or heifers (Tables 2, 3 and 4). So covariance involving muscle:bone ratio adjusted to common weights of bone was not legitimate in any of the three sex groups. In all other relationships involving muscle:bone ratio, the slopes were found to be homogeneous within sex groups. Moreover, the present study indicated significant differences in muscle:bone ratio among breed groups of bulls, steers or heifers even after adjustment was made for muscle, fat, muscle plus bone or cold carcass weights. Breed differences in muscle:bone ratio have been also cited by Hankins _et al._ (1942), Carrol _et al._ (1964) and Berg and Butterfield (1966). So it appears to be legitimate to compare groups of animals differing in

carcass weight through muscle:bone ratio if the rate of change of this ratio with changes in carcass weight in a breed is estimated and adjustment made.

Relationships involving percentage fat

Percentage fat tended to increase in all breeds of bulls, steers or heifers when various tissue weights, except bone, among the independent variables increased as indicated by positive regression coefficients (Tables 2, 3 and 4). This was probably a reflection of the tendency of heavier animals to have been fatter and of fat deposition to have been rapid relative to other tissues over the range of these data.

Among different breeds of bulls, steers or heifers (Tables 2, 3 and 4) the regression coefficients of percentage fat on muscle, fat and cold carcass weights were found to be heterogeneous indicating a diverse rate of fattening when the independent variables were held constant. But the slopes were homogeneous in all breeds of three sexes when percentage fat was regressed on either bone or muscle plus bone. There was a considerable breed variation in the percentage fat when adjusted by covariance for bone and muscle plus bone.

Among different breeds of bulls, HE contained the highest percentage fat which was followed by HY X HE and then by JR, HY and SH. HL had the lowest fat in their carcasses.

In the steer group, when adjusted by covariance to a common level of bone or muscle plus bone, HE, HY, HY X HE, HE X (A.G.) and SH contained higher, HE X HY intermediate and HL and BS lower percentages of fat in their carcasses respectively.

In the two groups of heifers, HE had a higher percentage of fat ($P<0.05$) compared with SH when adjusted to a common level of bone or muscle plus bone.

The present study indicates that there is a considerable breed variation in liveweight rate of fattening indicating that adjustment factors based on relationships of carcass weight to percentage fat for one group of animals are unlikely to be applicable to other groups differing in breeding or management. Adjustment factors must therefore be estimated from the data obtained from each group and experiments or performance tests should be designed in such a way that regression of percentage fat on carcass weight can be determined for each group. Interestingly percentage fat differences between groups was legitimately tested when adjusted to a common muscle plus bone weight. This agrees with results of Berg and Butterfield (1966).

(3) Sex influence on total, proportion of muscle, bone, fat and muscle:bone and muscle:fat ratio

In the present study sex influence on daily liveweight and tissue gain, and on total and proportion of component tissues has been appraised within five different breed groups (Table 5). In two breeds (HE and SH) three sexes (bulls, steers and heifers) were present. In the other breed groups (HY, HY X HE and HL) only bulls and steers were represented.

In all breed groups, average daily liveweight gain was higher in bulls compared with steers and in steers compared with heifers. This is in agreement with the findings of Brannang (1966) and King *et al.* (1965). Similar was the trend in muscle gain per day of age in all sex comparisons. Fat per day of age was not significantly different

TABLE 5

Among sex group test of significant differences on means of age, live weight, daily live weight and tissue gains, and of component tissues in five different breed groups

	Hereford				Hybrid			Hybrid X Hereford			Shorthorn cross				Holstein		
	Bulls	Steers	Heifers	Variance Ratio	Bulls	Steers	Variance Ratio	Bulls	Steers	Variance Ratio	Bulls	Steers	Heifers	Variance Ratio	Bulls	Steers	Variance Ratio
Number of Animals	13	11	10		17	16		5	16		12	22	12		8	6	
Age (days)	461	402	365	10.8**	443	433	0.2	388	434	6.8*	361	383	398	0.9	386	480	17.2**
Live Weight (kg)	466.2	373.9	305.5	34.1**	496.5	461.5	2.3	470.3	461.8	0.1	386.1	376.9	345.8	0.7	416.0	466.9	3.3
Live Gain/Day (kg)	1.02	0.93	0.84	13.3**	1.13	1.07	1.8	1.21	1.07	7.7**	1.06	0.98	0.86	13.8**	1.08	0.98	4.7*
Muscle/Day (kg)	0.18	0.15	0.13	17.6**	0.22	0.17	31.1**	0.21	0.17	36.4**	0.20	0.16	0.13	37.6**	0.20	0.16	16.2**
Fat/Day (kg)[1]	0.08	0.08	0.07	1.2	0.07	0.10	18.0**	0.09	0.09	0.1	0.06	0.08	0.08	5.3*	0.04	0.07	34.9**
1. Cold 1/2 carcass wt. (kg)	135.3	107.4	85.6	31.9**	145.4	133.4	2.6	135.9	131.7	0.3	107.8	97.2	98.2	0.3	111.1	127.7	4.9*
2. Muscle (kg)	80.4	61.7	49.2	58.2**	95.7	73.6	20.2**	80.9	74.1	2.4	73.1	61.8	53.9	4.4*	75.9	75.5	0.1
3. Bone (kg)	15.3	12.7	10.1	48.3**	17.3	15.7	4.9*	16.9	15.5	2.9	13.9	12.8	11.00	4.2*	18.3	18.2	0.2
4. Fat (kg)	37.4	31.8	25.9	4.8*	30.2	42.0	12.8**	35.9	40.4	0.8	23.8	30.6	31.1	1.9	14.9	31.8	37.8**
5. Percent Muscle	60.6	58.1	57.6	2.2	66.4	56.1	51.2**	60.6	56.8	2.6	64.9	58.9	57.1	34.2**	69.2	59.9	58.0**
6. Percent Bone	11.6	12.0	11.8	0.5	12.1	12.0	0.1	12.7	11.9	2.7	13.8	13.1	12.5	2.4	16.7	14.5	20.4**
7. Percent Fat	27.3	29.5	30.4	1.5	21.0	31.4	40.4**	26.1	30.8	2.8	21.1	28.4	31.2	29.0**	13.5	25.0	21.5**
8. Muscle:Bone Ratio	5.3	4.9	4.9	7.4**	5.5	4.7	19.9**	4.8	4.8	0.1	5.2	4.9	4.8	2.6	4.2	4.1	0.1
9. Muscle:Fat Ratio	2.3	2.0	1.9	2.6	3.3	1.9	30.2**	2.4	1.9	2.9	3.3	2.1	1.9	38.3**	5.2	2.4	91.2**

* Significant at $P<0.05$.
** Significant at $P<0.01$.
1 Any two means underscored by the same line are not significantly different at ($P<0.01$ or $P<0.05$).

among different sexes in HE and HY X HE groups. However, in HY, SH and HL breed groups daily rate of gain of fat was significantly lower in bulls compared with either steers or heifers.

HE bulls had a significantly ($P<0.01$ or $P<0.05$) higher cold carcass weight and total muscle, bone and fat which were followed by steers and heifers respectively. The proportion of tissues did not differ significantly among the 3 sexes which suggests that they were at similar stages of development even though at differing weights. Alternatively, and perhaps more sensibly, it would mean that HE bulls showed prolonged growth impetus for muscle and delayed onset of fattening as compared to steers which in turn showed a similar relationship to heifers. Sex exerted very little influence on bone development in this breed as indicated by similarity in their percentages. HE bulls had significantly ($P<0.01$) higher muscle:bone ratios over steers or heifers. Bulls were higher, steers intermediate and heifers low in muscle:fat ratio without showing any statistically significant differences.

In the comparison of HY bulls and steers the bulls were heavier at slaughter. Nevertheless the carcasses from steers were much fatter containing a higher total amount and percentage of fat. The bull carcasses had a higher percentage of muscle but differences in percentage of bone between bulls and steers were slight and non-significant. This particular breed group, contained a higher proportion of Charolais than other groups in Table 5 and showed a tendency to late fattening. This was particularly evident in the bulls which showed a prolonged muscle growth impetus and reached the highest muscle:bone ratios in the present study being quite superior in this regard to the compare-

able steers. Bulls were also favoured ($P < 0.01$) in muscle:fat ratio over steers.

HY X HE bulls and steers were slaughtered at similar liveweights and although no significant differences were detected in body composition the trend was similar to other breed groups with bulls having a higher percentage of muscle and a lower percentage of fat than steers. However neither muscle:bone nor muscle:fat ratio favoured bulls in this breed group.

In the SH groups, bulls and steers had similar carcass weights but the heifers had lighter carcasses. This resulted in differing composition between bulls and steers but not between steers and heifers indicating that the bulls were at a different stage of development than the steers and heifers. Bull carcasses had a higher percentage of muscle and a lower percentage of fat while percentage of bone differences did not reach a level of significance. The muscle:bone ratio did not differ significantly between the sexes but again it was higher for bulls over steers and steers over heifers. Bulls excelled ($P < 0.01$) in muscle:fat ratio over steers or heifers.

In the HL group, bulls, although significantly ($P < 0.05$) lower in carcass weight, contained higher proportions ($P < 0.01$) of lean, bone and a higher muscle:fat ratio and a lower amount ($P < 0.01$) of fat. The muscle:bone ratio was virtually the same in both groups.

In general when sexes are being compared with respect to carcass composition, it is clear that weight must be taken into consideration. Bulls seem to have a prolonged impetus for muscle growth and a tendency to fatten at heavier weights than steers and steers bear a similar relationship to heifers. At equal weights heifers would be fatter

than steers and steers fatter than bulls. However at equal percentages of fat in the carcass all three sexes could be very similar in carcass composition although quite different in carcass weights.

There is very little information in the literature about the influence of sex on the growth patterns of major tissues from total dissection data. However, a number of investigations studied sex differences on certain carcass characteristics which support indirectly the contentions of the present study in terms of sex influence on relative growth of component tissues.

Bradley et al. (1966) compared 34 steer and 34 heifer carcasses at carcass weights of 298 and 267 kg, respectively. The fat percentages estimated from the 9-11th rib-cut were 40.7 and 44.6 and muscle:bone ratios were 3.31 and 3.19, respectively. Breidenstein et al. (1963) compared 78 sides of steers with 93 sides of heifers. The side weights were similar for the sexes but heifers had a greater amount of waste indicating greater fatness. Prescott and Lamming (1964) compared steers castrated at seven months with bulls. The cold carcass weights were 218 and 229 kg for steers and bulls. The steers had 29.2% fat in the 10th rib-cut compared to 16.8% for the bulls and the steers were inferior in muscle:bone ratio of the same cut at 2.72 vs. 3.38 for bulls. Bailey et al. (1966) found similar results with steers and bulls at 254 and 259 kg carcass weight, respectively. The composition of 9-11th rib was 40.1 and 30.8% fat, and muscle:bone ratios were 2.79 and 2.97, respectively.

(4) Sex influence on regression coefficients and adjusted means from the relationships involving total muscle, muscle:bone ratio and percentage fat as dependent variables

Relationships involving total muscle

In Table 6 are shown regression coefficients and adjusted means involving muscle, bone, fat, muscle plus bone and cold carcass weights among different sexes within five different breed groups.

At a constant level of bone, the slopes were heterogeneous among different sexes in any of the five breeds. This would indicate that the growth rate of muscle relative to bone differed among sexes. Muscle deposition relative to fat also differed among sexes in all five breed groups.

Interestingly enough, when total muscle was regressed on muscle plus bone, regression coefficients were found to be homogeneous among different sex groups in all five breeds. Additionally, the positions of the slopes did not differ significantly between different sexes in any one of the five different sexes in any one of the five different breed groups. These results seem at variance with the muscle regressed on bone results but the large part to whole spuriousness may mask any differential muscle growth when muscle plus bone is used as a control dimension.

After adjustment was made in cold carcass weight by covariance, the slopes were found to be homogeneous among sexes in all five breed groups as when muscle plus bone was used. However, the positions of the slopes were significantly ($P<0.01$ or $P<0.05$) higher in bulls over steers and in steers over heifers. In this case rates of muscling were comparatively higher in bulls, intermediate in steers and low

in heifers within a breed when adjusted to common cold carcass weights. The greater percentage of fat in the cold carcass weight of heifers and steers probably brought about these results.

Relationships involving muscle:bone ratio

Regression coefficients and adjusted means involving muscle:bone ratio and muscle, bone, fat, muscle plus bone and cold carcass weights among different sexes within five different breed groups are also presented in Table 6.

The slopes were found to be heterogeneous among different sexes when muscle:bone ratio was regressed on total muscle or bone in all sex comparisons. This indicates that for a given increase in muscle or bone, muscle:bone ratio increased more in bulls than steers and more in steers than heifers. No further test on adjusted means was legitimate.

When adjusted to a constant level of fat by covariance, the slopes were found to be homogeneous and the positions of the slopes were significantly ($P < 0.01$ or $P < 0.05$) higher in bulls compared with steers and in steers over heifers in all possible sex comparisons. This would indicate that at similar levels of fattening bulls had higher muscle:bone ratios over steers and steers over heifers.

Again at constant levels of either muscle plus bone or cold carcass weights, the slopes were homogeneous among different sexes without showing any significant differences in their positions in any one of the five breeds. Although statistically non-significant, the general trend in the rates of increase in muscle:bone ratio tended to be comparatively greater and the positions of the slopes appeared to

TABLE 6

Among sex group comparisons of adjusted means ($\overline{y}'$) and regression coefficients (b) with total muscle weight, muscle:bone ratio and percentage fat as dependent variables in five different breeds

Dependent Variables			Total Muscle Weight				Muscle:Bone Ratio					Percentage Fat				
Independent Variables			Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight
Breed	Sex															
Hereford	Bulls	b	5.17	0.55	0.87	0.79	0.02	0.011	0.012	0.014	0.005	0.26	1.18	0.42	0.18	0.20
		$\overline{y}'$	69.44	78.14	65.41	70.85^a	5.16	5.35	5.23^a	5.12	5.14	25.34^a	26.30^a	25.00^a	25.01^a	22.80^a
	Steers	b	4.22	0.68	0.85	0.41	0.01	0.020	0.011	0.011	0.002	0.28	1.55	0.57	0.25	0.23
		$\overline{y}'$	62.66	61.85	65.20	63.40^c	5.01	4.86	4.94^c	5.06	5.03	29.98^c	29.62^c	30.01^c	30.00^c	30.35^c
	Heifers	b	4.12	0.73	0.84	0.34	0.02	0.040	0.040	0.010	0.011	0.31	1.65	0.60	0.27	0.29
		$\overline{y}'$	62.32	51.90	64.83	59.67^e	4.94	4.80	4.88^c	4.92	4.90	32.49^e	31.64^e	33.00^e	32.10^e	35.39^e
Variance ratio: Between slopes			4.97*	10.12**	0.83	1.21	5.67**	4.57*	0.21	0.35	0.14	2.55	3.14	1.98	1.90	3.01
Between intercepts			----	----	2.18	6.71**	----	----	4.50*	1.47	1.79	5.72**	6.74**	9.09**	5.05*	6.30**
Hybrid	Bulls	b	6.65	0.94	0.91	0.71	0.03	0.087	0.003	0.024	0.016	0.08	0.27	0.38	0.05	0.01
		$\overline{y}'$	91.70	98.93	84.43	92.24	5.21	5.52	5.57	5.24	5.56	21.52	22.44	23.39	22.91	20.64
	Steers	b	3.10	0.37	0.84	0.39	0.01	0.096	0.008	0.006	0.005	0.09	0.32	0.43	0.09	0.19
		$\overline{y}'$	77.84	70.16	83.64	77.27	4.97	4.72	4.67	4.94	4.78	30.86	31.19	28.89	30.69	31.78
Variance ratio: Between slopes			5.07*	20.06**	3.03	1.32	4.21*	4.13*	0.84	2.09	2.05	1.05	0.02	0.24	0.84	1.20
Between intercepts			----	----	2.23	10.69**	----	----	17.65**	2.90	3.30	19.42**	19.51**	20.63**	12.03**	20.21**
Hybrid X Hereford	Bulls	b	4.68	0.64	0.88	0.41	0.02	0.001	0.001	0.018	0.005	0.30	2.56	0.37	0.29	0.12
		$\overline{y}'$	76.02	81.16	75.76	79.60	4.71	4.80	4.78	4.80	4.78	27.18	26.87	27.83	27.17	25.61
	Steers	b	4.65	0.23	0.85	0.41	0.01	0.004	0.005	0.009	0.002	0.45	1.95	0.57	0.38	0.18
		$\overline{y}'$	75.62	74.00	75.56	74.50	4.80	4.78	4.80	4.72	4.78	30.49	30.59	30.27	30.50	30.94
Variance ratio: Between slopes			6.12*	5.19*	0.50	0.34	6.22**	5.62*	0.26	0.48	0.12	2.34	1.56	3.42	2.10	0.14
Between intercepts			----	----	0.23	4.45*	----	----	5.67*	0.32	0.01	8.90**	8.88**	4.52*	5.65*	4.61*

continued

TABLE 6 (continued)

Among sex group comparisons of adjusted means ($\overline{y}'$) and regression coefficients (b) with total muscle weight, muscle:bone ratio and percentage fat as dependent variables in five different breeds

Dependent Variables			Total Muscle Weight				Muscle:Bone Ratio					Percentage Fat				
Independent Variables			Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight
Breed	Sex															
Shorthorn cross	Bulls	b	6.47	1.77	0.89	0.46	0.021	0.121	0.041	0.018	0.012	0.10	0.72	0.24	0.08	0.05
		$\overline{y}'$	65.35^{a}	79.84	62.43	70.44^{a}	5.08	5.07	5.21^{a}	5.09	5.01	19.62^{a}	20.00^{a}	22.56^{a}	19.94	20.66^{a}
	Steers	b	6.06	1.34	0.86	0.44	0.021	0.112	0.031	0.018	0.008	0.13	0.75	0.26	0.11	0.07
		$\overline{y}'$	63.68^{c}	59.62	62.07	62.85^{c}	4.89	4.95	4.85^{c}	4.90	4.93	28.53^{c}	28.19^{c}	27.94^{c}	28.36	28.58^{c}
	Heifers	b	5.01	0.98	0.85	0.43	0.019	0.101	0.022	0.015	0.006	0.32	0.91	0.35	0.27	0.15
		$\overline{y}'$	60.71^{e}	51.16	61.86	54.64^{e}	4.81	4.79	4.77^{c}	4.81	4.84	32.47^{e}	32.62^{e}	30.62^{e}	32.37	31.33^{e}
Variance ratio: Between slopes			5.56**	4.83*	2.64	2.86	6.18**	5.80**	0.89	0.087	0.014	1.92	1.42	2.06	1.05	2.32
Between intercepts			----	----	2.68	9.49**	----	----	5.72**	2.40	0.90	10.21**	59.71**	74.23**	20.03**	10.45**
Holstein	Bulls	b	2.48	1.29	0.77	0.57	0.03	0.890	0.041	0.008	0.021	0.08	0.06	0.27	0.06	0.07
		$\overline{y}'$	75.84	85.70	75.78	80.11	4.16	4.16	4.34	4.16	4.24	13.51	13.50	15.73	13.51	14.03
	Steers	b	1.44	0.25	0.93	0.30	0.02	0.141	0.032	0.022	0.012	0.09	0.10	0.58	0.08	0.08
		$\overline{y}'$	75.69	62.49	75.73	69.95	4.15	4.15	3.91	4.15	4.07	24.98	24.99	22.01	24.98	24.28
Variance ratio: Between slopes			6.01*	6.64*	1.25	0.14	5.03*	7.70**	0.09	4.09	2.31	0.01	1.87	2.07	0.01	0.01
Between intercepts			----	----	0.90	12.43**	----	----	6.61**	0.01	1.81	23.43**	26.55**	21.24**	12.48**	82.88**

* Significant at ($P < 0.05$).

** Significant at ($P < 0.01$).

---- Missing values indicate analyses of covariance and comparisons of adjusted means not legitimate.

a c e adjusted means within breed and in a column having different superscript differ significantly at ($P < 0.01$ or $P < 0.05$).

$\overline{y}'$ indicates independent variable adjusted to overall mean of X(muscle = 65.15, 62.06, 84.98, 75.71, 75.75 kg; bone = 12.90, 12.58, 16.51, 15.83, 18.21 kg; fat = 32.19, 28.96, 35.90, 39.36, 22.12 kg; muscle plus bone = 78.06, 74.64, 100.51, 91.54, 93.97; cold carcass wt. = 111.66, 100.18, 139.59, 132.70, 118.25 kg in Hereford, Hybrid, Hybrid X Hereford, Shorthorn cross and Holstein breeds respectively).

be higher in bulls, intermediate in steers and low in heifers when adjusted to a common level of muscle plus bone or cold carcass weights.

Relationships involving percentage fat

Table 6 also relates percentage fat to muscle, bone, fat, muscle plus bone and cold carcass weights among sexes within five different breed groups.

The slopes were found homogeneous over all possible relationships among sexes within five different breed groups. However, in all sex comparisons the rate of fattening (b-values) tended to be higher for heifers than for steers and for steers higher than for bulls. This reflects a tendency of heifers to become fatter faster compared to steers and steers compared to bulls with a corresponding increase in all other independent variables.

The positions of slopes when adjusted to common levels of all independent variables were significantly different among sexes within all breed groups. At equal weights of the independent variables heifers had higher weights of fat than steers and steers were fatter than bulls. This indicates that fattening was earlier in heifers compared to steers and steers compared to bulls although, as mentioned above, the relative rate of fattening was not significantly different among sexes.

B. Muscle weight distribution and growth patterns of anatomical muscle groups

(1) Muscle weight distribution in beef cattle

Muscle is the major and most valuable component of a carcass. Considerable emphasis has been placed in the past on live conformation in selection of beef cattle stressing the point that superior conformation implies a high proportion of lean meat to bone and higher proportion of weight of carcass in more valuable parts (Warwick, 1963; U.S.D.A., 1965). If these claims are sound, there should be variations in the muscle weight distribution between breeds. To study the effect of breed and sex on muscle weight distribution, the individual muscles were classified into nine groups according to anatomical locations on the carcass (Butterfield, 1963). The locations of these nine groups are diagrammed in Figure 1.

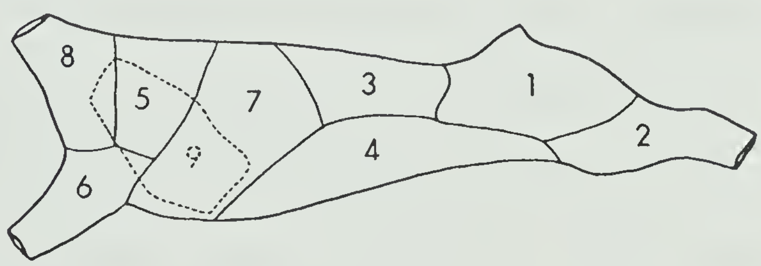

Figure 1. Standard bovine anatomical muscle groups

1. Proximal pelvic limb
2. Distal pelvic limb
3. Surrounding spinal column
4. Abdominal region
5. Proximal thoracic limb
6. Distal thoracic limb
7. Thorax to thoracic limb
8. Neck to thoracic limb
9. Neck and thorax

The names of the individual muscles constituting each group are given in Appendix Table 1. Certain tail muscles, diaphragm and scrap muscles were lumped into muscle group 10 which was termed as scrap.

Expensive muscles of Group 11 are the sum of Groups 1 and 3 representing a compromise between anatomy and high priced butchers' cuts in Canada. Expensive muscles of Group 12 are the sum of the muscles belonging to Groups 1, 3 and 5 which constitute the high priced cuts in Australia (Butterfield, 1963) and in some European countries.

Muscle weight distribution was measured by the proportion of total muscle found in each of the nine anatomical groups. Breed and sex differences in the percentage means were tested by one-way analysis of variance.

a) Influence of breed

Breed differences occurred in muscle Groups 4 (abdominal region) and 9 (neck and thorax) in bulls and steers (Table 7). There were no differences in muscle percentages of any anatomical groupings between the two heifer breed groups. HL and JR bulls had significantly ($P < 0.01$) higher proportions of muscles in the abdominal region compared with HY X HE, HE and SH which was followed by HY. These results corroborate the findings of Butterfield (1963) and Harte (1967, 1968) with respect to different breeds of steers. Since some of the abdominal muscles are invariably associated with inseparable (through dissection) inter- and intra-muscular fat, this may reflect the early onset of fattening specially in the abdominal region in some breeds compared to the other. It is difficult to conclude anything specifically without chemical analysis of the muscle from this region.

Muscle group 9 (neck and thorax) represents late developing muscles (Butterfield and Berg, 1966) and breed differences in this group probably reflect different stages of development among the

TABLE 7

Means and standard deviations of anatomical muscle groups as percentage of total muscle from different breed groups of bulls, steers and heifers

Sex	Anatomical groups	1 Proximal pelvic limb	2 Distal pelvic limb	3 Surrounding spinal column	4 Abdominal region	5 Proximal thoracic limb	6 Distal thoracic limb	7 Thorax to thoracic limb	8 Neck to thoracic limb	9 Neck & thorax	10 Scrap muscles	11 Expensive muscles[1]	12 Expensive muscles[2]
Sex	Breed groups												
Bulls	Hereford	28.4	4.5	12.4	9.8^b	12.4	2.2	10.3	5.6	12.4^b	1.8^b	40.8	53.3
	Hybrid	28.3	4.4	12.7	8.5^c	12.2	2.2	10.7	5.7	13.0^a	2.5^a	41.0	53.1
	Hybrid X Hereford	28.3	4.2	12.4	10.0^b	12.7	2.3	10.7	5.5	11.7^c	2.2^b	40.7	53.4
	Shorthorn cross	28.4	4.1	12.4	10.0^b	12.5	2.3	10.2	5.4	12.1^b	3.0^a	40.8	53.3
	Holstein	28.8	4.3	12.1	10.9^a	12.8	2.5	10.7	5.0	11.1^c	2.0^b	40.8	53.6
	Jersey	28.4	4.0	12.1	10.6^a	12.6	2.4	10.4	5.3	13.0^a	1.0^c	40.5	53.2
	Pooled standard deviations:	1.12	0.30	0.59	0.69	0.55	0.17	0.61	0.51	0.98	0.79	1.14	1.20
	Variance ratios:	1.74	2.35	2.14	4.58**	1.25	1.16	1.46	1.72	4.02**	3.84**	2.17	1.89
Steers	Hereford	29.5	4.3	12.3	10.8^b	12.5	2.4	10.0	5.2	10.4^a	2.7^a	41.7	54.2
	Hybrid	29.9	4.3	11.9	10.5^b	12.9	2.4	10.7	5.5	10.4^a	1.5^b	41.8	54.7
	Hereford X Hybrid	29.9	4.5	12.1	10.3^b	12.9	2.4	10.9	5.1	10.5^a	1.4^b	42.0	54.9
	Hybrid X Hereford	29.1	4.4	12.6	10.3^b	12.4	2.4	11.0	6.0	10.5^a	1.3^b	41.7	54.2
	Hereford X (A.G.)	29.5	4.4	12.4	10.7^b	12.9	2.4	10.3	5.1	10.5^a	1.8^b	41.9	54.8
	Shorthorn cross	29.6	4.3	12.3	11.8^a	12.3	2.4	10.6	5.1	9.5^b	2.0^a	41.9	54.2
	Brown Swiss cross	29.6	4.4	12.2	10.6^b	12.9	2.4	10.7	5.2	10.3^a	1.6^b	41.8	54.7
	Holstein	29.6	4.2	12.3	11.3^a	12.5	2.5	10.4	5.1	9.4^b	2.7^a	41.9	54.4
	Pooled standard deviations:	1.12	0.28	0.45	0.74	0.39	0.14	0.47	0.39	0.84	0.88	1.10	1.15
	Variance ratios:	1.68	1.72	1.73	5.97**	2.17	0.75	2.10	0.77	4.48**	11.72**	2.01	1.95

continued...

TABLE 7 (continued)

Means and standard deviations of anatomical muscle groups as percentage of total muscle from different breed groups of bulls, steers and heifers

Sex	Anatomical groups	1 Proximal pelvic limb	2 Distal pelvic limb	3 Surrounding spinal column	4 Abdominal region	5 Proximal thoracic limb	6 Distal thoracic limb	7 Thorax to thoracic limb	8 Neck to thoracic limb	9 Neck & thorax	10 Scrap muscles	11 Expensive muscles[1]	12 Expensive muscles[2]
Sex	Breed groups												
Heifers	Hereford	31.3	4.2	12.2	11.7	12.5	2.1	10.5	5.1	9.1	1.2	43.5	56.0
	Shorthorn cross	31.6	4.4	12.1	11.4	12.4	2.3	10.2	5.2	9.0	1.4	43.7	56.1
	Pooled standard deviations:	1.22	0.32	0.59	0.82	0.33	0.14	0.42	0.28	0.49	0.54	1.10	1.16
	Variance ratios:	1.81	2.03	2.49	1.94	3.10	1.27	0.03	2.27	1.96	2.10	0.15	0.23

** Significant at ($P < 0.01$).
1 Sum of group 1 plus 3.
2 Sum of group 1 plus 3 plus 5.
a b c means in the same column and sex group having different superscript differ significantly at ($P < 0.01$ or $P < 0.05$).

breeds represented.

Scrap muscles differed significantly ($P < 0.01$) among breed groups of bulls and steers. This may be mainly attributed to the bilateral asymmetry of the diaphragm developed during the process of splitting the carcass into two equal halves. However, two breeds of heifers did not reach a significance level in this group.

When muscles were grouped into expensive classes, breed groups showed similar percentages in each sex. This further supports the hypothesis that breed differences in the proportion of lean meat in high priced regions of the carcass are minimal.

b) Influence of sex

Sex exerted a strong influence on the percentage of muscles in the proximal pelvic limb (Group 1), the abdominal region (Group 4), and the neck and thorax region (Group 9, Table 8). In Group 1 heifers had a significantly higher proportion of lean than steers and steers were higher than the entire males. This is contrary to normal convictions of breeders who would be inclined to expect a reversal of these results.

Sex influence was very conspicuous in muscles of the abdominal region with heifers having higher proportions over steers and steers higher over entire males. This again is perhaps a reflection of early onset of fattening in heifers compared with steers and steers compared with bulls. These results are in line with the findings of Bradley et al. (1966), Brannang (1966), Breidenstein et al. (1963) and Prescott and Lamming (1964).

In the neck and thorax region (Group 9) bulls contained a higher

TABLE 8

Among sex group comparisons of anatomical muscle groups from five different breeds

Breed groups	Hereford				Hybrid			Hybrid X Hereford			Shorthorn cross				Holstein		
Sex	Bulls	Steers	Heifers	Variance Ratios	Bulls	Steers	Variance Ratios	Bulls	Steers	Variance Ratios	Bulls	Steers	Heifers	Variance Ratios	Bulls	Steers	Variance Ratios
<u>Anatomical muscle groups</u>:																	
1. Proximal pelvic limb	28.4	29.5	31.3	19.56**	28.3	29.9	6.00**	28.3	29.1	8.32**	28.4	29.6	31.6	7.52**	28.8	29.6	9.71**
2. Distal pelvic limb	4.5	4.3	4.2	3.12	4.4	4.3	1.68	4.2	4.4	2.01	4.1	4.3	4.4	2.22	4.3	4.2	2.44
3. Surrounding spinal column	12.4	12.3	12.2	2.32	12.7	11.9	1.77	12.4	12.6	0.10	12.4	12.3	12.1	0.29	12.1	12.3	0.65
4. Abdominal region	9.8	10.8	11.7	4.72**	8.5	10.5	10.86**	10.0	10.3	26.72**	10.0	11.8	11.4	5.01**	10.9	11.3	15.89**
5. Proximal thoracic limb	12.4	12.5	12.5	1.51	12.2	12.9	2.79	12.7	12.4	0.02	12.5	12.3	12.4	0.02	12.8	12.5	1.21
6. Distal thoracic limb	2.2	2.4	2.1	2.01	2.2	2.4	2.83	2.3	2.4	1.85	2.3	2.4	2.3	2.42	2.5	2.5	0.78
7. Thorax to thoracic limb	10.3	10.0	10.5	2.17	10.7	10.7	1.74	10.7	11.0	2.32	10.2	10.6	10.2	0.02	10.7	10.4	2.38
8. Neck to thoracic limb	5.6	5.2	5.1	3.01	5.7	5.5	3.09	5.5	6.0	2.99	5.4	5.1	5.2	4.43	5.0	5.1	2.45
9. Neck & thorax	12.4	10.4	9.1	65.23**	13.0	10.4	37.52**	11.7	10.5	15.01**	12.1	9.5	9.0	5.67**	11.1	9.4	10.97**
10. Scrap muscles	1.8	2.7	1.2	8.07**	2.4	1.5	18.33**	2.2	1.3	6.05**	3.0	2.0	1.4	8.01**	2.0	2.7	11.01**
11. Expensive muscles	40.8	41.7	43.5	26.05**	41.0	41.8	12.32**	40.7	41.7	9.77**	40.8	41.9	43.7	9.21**	40.8	41.9	15.86**
12. Expensive muscles	53.3	54.2	56.0	18.72**	53.1	54.7	8.07**	53.4	54.2	8.27**	53.3	54.2	56.1	8.17**	53.6	54.4	6.56*

* Significantly different at ($P < 0.05$).

** Significantly different at ($P < 0.01$).

proportion of muscles than steers which were higher than heifers. These muscles reflect secondary sex influences and may be the result of protein accretion effects of testosterone as noted by Brannang in cattle (1966), Kochakian and Tilloston in guinea pigs (1957), Prescott and Lamming (1964) and Prescott (1969) in sheep.

Proportions of expensive muscle groups (Groups 11 and 12) were strongly influenced by sex. Heifers contained significantly ($P < 0.01$) higher proportion of muscles in the high priced regions compared with steers and steers over bulls. This was despite the fact that by visual judgement one would probably expect the opposite.

The present experiment made it quite obvious that selection for conformation through visual appraisal has not been fruitful in changing the lean tissue distribution in a desired direction. There were significant breed and sex differences in the neck, abdominal and proximal hind regions which could be related to normal physiological processes of growth.

(2) Influence of breed and sex on the total muscle weights of nine anatomical groups

In this section influence of breed and sex on the weights of total muscle of each of the nine anatomical groups has been studied when total muscle in the side of a carcass was held constant by one-way analysis of covariance.

a) Influence of breed

The relative growth pattern was significantly different in abdominal (Group 4) and neck and thorax (Group 9) regions among divergent breed groups of bulls and steers (Tables 9 and 10). No such

TABLE 9

Regression coefficients with standard errors ($b \pm S.E.$) and adjusted means ($\bar{y}'$) from the relationships involving muscles in anatomical groups with total muscle weights in bulls

Group No.		1	2	3	4	5	6	7	8	9
Anatomical groups		Proximal hind limb	Distal hind limb	Surrounding spinal column	Abdominal region	Proximal thoracic limb	Distal thoracic limb	Thorax to thoracic limb	Neck to thoracic limb	Neck & thorax
Hereford	$b \pm S.E.$	0.24 ± 0.03	0.03 ± 0.001	0.12 ± 0.01	0.10 ± 0.02	0.11 ± 0.01	0.01 ± 0.001	0.11 ± 0.01	0.01 ± 0.001	0.14 ± 0.02
	$\bar{y}'$	22.64	3.08	9.22	7.67	9.72	1.76	8.04	4.38	9.46
Hybrid	$b \pm S.E.$	0.24 ± 0.01	0.03 ± 0.001	0.13 ± 0.01	0.10 ± 0.01	0.13 ± 0.01	0.01 ± 0.001	0.12 ± 0.01	0.01 ± 0.002	0.12 ± 0.02
	$\bar{y}'$	22.58	3.21	9.24	7.31	9.42	1.77	8.26	4.27	9.08
Hybrid X Hereford	$b \pm S.E.$	0.23 ± 0.02	0.04 ± 0.002	0.12 ± 0.02	0.10 ± 0.02	0.12 ± 0.01	0.03 ± 0.002	0.12 ± 0.02	0.01 ± 0.002	0.14 ± 0.01
	$\bar{y}'$	22.90	3.32	9.45	7.56	9.33	1.73	8.83	4.23	9.36
Shorthorn cross	$b \pm S.E.$	0.25 ± 0.01	0.03 ± 0.001	0.12 ± 0.02	0.11 ± 0.01	0.12 ± 0.01	0.02 ± 0.001	0.11 ± 0.01	0.01 ± 0.001	0.13 ± 0.01
	$\bar{y}'$	22.81	3.02	9.90	7.92	9.44	1.71	8.09	4.44	9.69
Holstein	$b \pm S.E.$	0.24 ± 0.05	0.04 ± 0.001	0.12 ± 0.03	0.11 ± 0.04	0.11 ± 0.03	0.03 ± 0.001	0.11 ± 0.02	0.01 ± 0.001	0.17 ± 0.03
	$\bar{y}'$	22.04	3.30	9.41	8.01	9.68	1.71	8.61	4.21	10.01
Jersey	$b \pm S.E.$	0.24 ± 0.04	0.03 ± 0.002	0.13 ± 0.02	0.11 ± 0.02	0.11 ± 0.02	0.01 ± 0 001	0.12 ± 0.01	0.02 ± 0.001	0.16 ± 0.04
	$\bar{y}'$	22.22	3.37	9.93	8.37	9.42	1.77	8.66	4.72	10.28
Variance ratios:										
Between slopes		0.43	0.90	1.69	4.61**	1.88	1.49	1.53	0.78	4.91**
Between intercepts		1.72	1.93	1.38	----	1.02	1.92	1.37	1.78	----

** Significant at ($P < 0.01$).
$\bar{y}'$ indicates dependent variable adjusted to over all mean of X (total muscle = 78.09 kg).

TABLE 10

Regression coefficients with standard errors (b$\pm$S.E.) and adjusted means ($\bar{y}'$) from the relationships involving muscles in anatomical groups with total muscle weights in steers

Group No.		1	2	3	4	5	6	7	8	9
Anatomical groups		Proximal hind leg	Distal hind leg	Surrounding spinal column	Abdominal region	Proximal thoracic limb	Distal thoracic limb	Thorax to thoracic limb	Neck to thoracic limb	Neck & thorax
Hereford	b$\pm$S.E.	0.28 $\pm$ 0.05	0.04 $\pm$ 0.001	0.13 $\pm$ 0.03	0.11 $\pm$ 0.04	0.11 $\pm$ 0.01	0.03 $\pm$ 0.001	0.10 $\pm$ 0.02	0.01 $\pm$ 0.001	0.11 $\pm$ 0.02
	$\bar{y}'$	20.44	3.43	8.73	7.53	8.41	1.63	7.00	3.60	7.16
Hybrid	b$\pm$S.E.	0.27 $\pm$ 0.02	0.03 $\pm$ 0.001	0.13 $\pm$ 0.02	0.11 $\pm$ 0.01	0.11 $\pm$ 0.01	0.02 $\pm$ 0.002	0.10 $\pm$ 0.01	0.01 $\pm$ 0.002	0.11 $\pm$ 0.03
	$\bar{y}'$	20.52	3.03	8.38	7.21	8.51	1.66	7.03	3.43	7.29
Hereford X Hybrid	b$\pm$S.E.	0.28 $\pm$ 0.05	0.03 $\pm$ 0.001	0.12 $\pm$ 0.01	0.12 $\pm$ 0.02	0.10 $\pm$ 0.01	0.02 $\pm$ 0.001	0.12 $\pm$ 0.03	0.02 $\pm$ 0.001	0.10 $\pm$ 0.02
	$\bar{y}'$	20.88	3.14	8.40	7.17	8.32	1.68	7.10	3.54	7.03
Hybrid X Hereford	b$\pm$S.E.	0.27 $\pm$ 0.03	0.04 $\pm$ 0.002	0.13 $\pm$ 0.01	0.11 $\pm$ 0.02	0.11 $\pm$ 0.01	0.03 $\pm$ 0.001	0.10 $\pm$ 0.02	0.01 $\pm$ 0.001	0.10 $\pm$ 0.02
	$\bar{y}'$	20.36	3.11	8.07	7.12	8.48	1.70	7.01	3.49	7.31
Hereford X (A.G.)	b$\pm$S.E.	0.28 $\pm$ 0.04	0.04 $\pm$ 0.002	0.12 $\pm$ 0.01	0.12 $\pm$ 0.04	0.11 $\pm$ 0.02	0.02 $\pm$ 0.002	0.11 $\pm$ 0.02	0.01 $\pm$ 0.002	0.10 $\pm$ 0.04
	$\bar{y}'$	20.85	3.03	8.31	7.47	8.32	1.66	7.19	3.56	7.33
Shorthorn cross	b$\pm$S.E.	0.28 $\pm$ 0.01	0.03 $\pm$ 0.001	0.12 $\pm$ 0.03	0.13 $\pm$ 0.01	0.12 $\pm$ 0.01	0.02 $\pm$ 0.002	0.10 $\pm$ 0.01	0.01 $\pm$ 0.002	0.12 $\pm$ 0.04
	$\bar{y}'$	20.54	3.02	8.74	7.87	8.32	1.64	7.09	3.74	7.38
Brown Swiss cross	b$\pm$S.E.	0.28 $\pm$ 0.03	0.03 $\pm$ 0.002	0.13 $\pm$ 0.01	0.11 $\pm$ 0.02	0.11 $\pm$ 0.01	0.02 $\pm$ 0.001	0.01 $\pm$ 0.01	0.02 $\pm$ 0.001	0.11 $\pm$ 0.02
	$\bar{y}'$	20.66	3.12	8.47	7.28	8.38	1.71	7.12	3.56	7.22
Holstein	b$\pm$S.E.	0.28 $\pm$ 0.02	0.04 $\pm$ 0.001	0.12 $\pm$ 0.01	0.15 $\pm$ 0.01	0.11 $\pm$ 0.01	0.03 $\pm$ 0.001	0.11 $\pm$ 0.01	0.01 $\pm$ 0.001	0.13 $\pm$ 0.03
	$\bar{y}'$	20.69	3.15	8.51	7.93	8.79	1.70	7.02	3.50	7.43
Variance ratios:										
Between slopes		1.01	1.12	1.31	3.72**	0.89	1.18	0.65	1.31	4.75**
Between intercepts		1.70	0.78	1.01	----	1.77	1.15	3.40	1.91	----

** Significant at ($P < 0.01$).
$\bar{y}'$ indicates dependent variable adjusted to over all mean of X (total muscle = 69.71 kg).

TABLE 11

Regression coefficients with standard errors ($b \pm S.E.$) and adjusted means ($\overline{y}'$) from the relationships involving muscles in anatomical groups with total muscle weights in heifers

Group No.		1	2	3	4	5	6	7	8	9
Anatomical groups		Proximal hind limb	Distal hind limb	Surrounding spinal column	Abdominal region	Proximal thoracic limb	Distal thoracic limb	Thorax to thoracic limb	Neck to thoracic limb	Neck & thorax
Hereford	$b \pm S.E.$	0.30 ± 0.04	0.05 ± 0.01	0.12 ± 0.02	0.12 ± 0.01	0.13 ± 0.01	0.03 ± 0.001	0.11 ± 0.01	0.01 ± 0.001	0.10 ± 0.02
	$\overline{y}'$	15.30	2.35	6.30	5.12	6.19	1.25	5.06	2.39	5.20
Shorthorn cross	$b \pm S.E.$	0.29 ± 0.01	0.03 ± 0.01	0.14 ± 0.01	0.14 ± 0.01	0.11 ± 0.01	0.02 ± 0.001	0.11 ± 0.03	0.01 ± 0.002	0.11 ± 0.01
	$\overline{y}'$	15.11	2.24	6.69	5.43	6.01	1.16	5.02	2.49	5.33
Variance ratios:										
Between slopes		2.00	1.37	1.10	1.31	1.22	1.68	0.01	0.36	0.31
Between intercepts		0.69	0.67	0.52	0.86	5.78	1.01	0.30	0.48	0.78

$\overline{y}'$ indicates dependent variable adjusted to over all mean of X (total muscle = 51.00).

difference was found between the two breeds of heifers (Table 11). In all other anatomical groups the relative growth pattern was similar among different breeds of all three sexes as indicated by the homogeneity of slopes.

When adjusted by covariance to a constant level of muscle, breed groups did not show any significant difference in the muscles of different anatomical locations. However, in bull and steer groups, this could not be tested in Group 4 and Group 9 muscles because of heterogeneous nature of the slopes.

b) Influence of sex

Sex differences on the total muscle weights of nine anatomical groups were also appraised in five different breed groups (Table 12). There was a general trend of heifers being non-significantly higher in Groups 1 and 4 over steers and steers over heifers and a reverse order of sex influence in the muscles of Group 9.

The findings of this section supports the results of the preceding chapter.

Several factors e.g. nutrition, type and conformation of cattle, breed differences and exercise could influence the muscle weight distribution. It appears quite pertinent to discuss elaborately the influence of these factors in the same order on lean tissue distribution.

The remarkable similarity in the proportionate yield of retail cuts over nine different breeds of steers was first shown by Wilson and Curtis as early as 1893 (Wilson and Curtis, 1893). In their experiment, difference in nutritional regimes did not make any

TABLE 12

Among sex group comparisons of total muscle weights from anatomical groups in five breeds

Breed		Hereford				Hybrid			Hybrid X Hereford			Shorthorn cross				Holstein		
Sex group		Bulls	Steers	Heifers	Variance Ratios	Bulls	Steers	Variance Ratios	Bulls	Steers	Variance Ratios	Bulls	Steers	Heifers	Variance Ratios	Bulls	Steers	Variance Ratios
1. Proximal pelvic limb	b	0.24	0.28	0.30	0.81	0.24	0.27	0.24	0.23	0.27	3.28	0.25	0.28	0.29	4.10	0.24	0.28	0.13
	$\bar{y}'$	18.07	18.65	18.74	1.17	24.46	24.82	0.80	22.03	22.10	0.01	17.66	18.00	18.36	8.26**	22.10	22.15	0.04
2. Distal pelvic limb	b	0.03	0.04	0.05	2.19	0.03	0.03	0.26	0.04	0.04	1.07	0.03	0.03	0.03	1.94	0.04	0.04	0.21
	$\bar{y}'$	2.60	2.73	2.74	0.59	3.40	3.54	2.29	3.17	3.39	2.30	2.58	2.59	2.65	0.87	3.12	3.21	2.40
3. Surrounding spinal column	b	0.12	0.13	0.12	1.41	0.13	0.13	0.01	0.12	0.13	8.64**	0.12	0.12	0.14	5.28**	0.12	0.12	3.27
	$\bar{y}'$	7.52	7.88	7.84	1.35	10.10	10.36	1.58	8.77	8.89	----	7.67	7.75	8.28	----	8.98	9.15	0.83
4. Abdominal region	b	0.10	0.11	0.12	0.41	0.10	0.11	3.19	0.10	0.11	0.47	0.11	0.13	0.14	1.74	0.11	0.15	4.41
	$\bar{y}'$	6.16	6.24	6.43	0.18	8.10	8.97	1.46	7.23	7.90	0.23	6.14	6.62	6.79	7.52**	6.63	7.46	11.23**
5. Proximal thoracic limb	b	0.11	0.11	0.13	0.93	0.13	0.11	0.99	0.12	0.11	7.65**	0.12	0.12	0.11	3.39*	0.11	0.11	1.01
	$\bar{y}'$	8.15	7.78	7.66	2.36	10.43	10.48	0.06	8.88	9.15	----	7.49	7.45	7.20	----	9.49	9.34	0.98
6. Distal thoracic limb	b	0.01	0.03	0.03	6.95**	0.01	0.02	1.46	0.03	0.03	0.01	0.02	0.02	0.02	2.74	0.03	0.03	0.01
	$\bar{y}'$	1.59	1.54	1.59	----	1.89	1.97	1.69	1.75	1.84	2.77	1.42	1.47	1.37	10.18**	1.86	1.87	0.02
7. Thorax to thoracic limb	b	0.11	0.10	0.11	0.15	0.12	0.10	1.08	0.12	0.10	0.67	0.11	0.10	0.11	2.01	0.11	0.11	0.58
	$\bar{y}'$	6.61	6.46	6.40	0.44	9.09	8.83	1.17	7.74	7.58	0.38	6.33	6.23	6.18	1.23	7.22	7.02	0.77
8. Neck to thoracic limb	b	0.01	0.01	0.01	0.48	0.01	0.01	0.11	0.01	0.01	0.06	0.01	0.01	0.01	0.90	0.01	0.01	0.66
	$\bar{y}'$	3.31	3.12	3.07	1.21	4.77	4.60	2.29	4.10	3.87	2.95	3.34	3.25	3.19	0.62	3.81	3.76	0.01
9. Neck & thorax	b	0.14	0.11	0.10	4.10*	0.12	0.11	0.60	0.14	0.10	3.33	0.13	0.12	0.11	14.66**	0.17	0.13	1.18
	$\bar{y}'$	7.52	7.01	6.86	----	10.31	9.08	6.44**	8.27	7.88	0.94	7.32	6.52	6.51	----	8.29	7.73	2.83

* Significant at ($P < 0.05$).
** Significant at ($P < 0.01$).
Means underscored by the same line in a row do not differ significantly at ($P < 0.01$ or $P < 0.05$).
$\bar{y}'$ indicates dependent variable adjusted to over all mean of X (total muscle in Hereford = 64.14 kg; Hybrid = 85.83 kg; Hybrid X Hereford = 75.71 kg; Shorthorn cross = 62.06 kg and Holstein = 74.56 kg).

appreciable change (less than 1%) in any one of the cuts between different breeds or within a breed. In an identical twin steer study, Yeates (1964) created a difference of 640 lbs. at slaughter weight between two animals by severe restriction of diet in one. Interestingly enough, the proportions of preferred cuts in carcasses of the twin steers was virtually unchanged (47.2 vs. 47.2%). Barton and Kirton (1962) estimated the proportion of muscles in each of seven joints from two groups of Friesian calves fed differently and slaughtered at a liveweight of approximately 203 lb. They found slight differences in the proportionate yield of muscular tissue in loin (3.26 vs. 3.61%) and rib cut (2.03 vs. 2.20%) between two treatments. Harte (1968) compared the distribution of "lean meat" from animals restricted in feed intake during the first 6 months of life and then re-alimented with animals fed _ad libitum_ throughout their life. There was no significant difference between treatments in this trait. Callow (1962) found little or no significant effect of level of nutrition on the distribution of muscular tissue among the joints. These seem to indicate, though not very precisely, that nutrition has very little effect on muscle distribution in beef cattle.

If selection was really effective in changing the muscle weight distribution in cattle, there should be a gross difference in this particular trait between dairy-type and beef-type in cattle. Wilson and Curtis (1893) did not find any appreciable differences in the yield of proportionate retail cuts between Hereford, Friesian and Jersey breeds. Branaman _et al._ (1962) compared different carcass characteristics between 25 Hereford and 25 Holstein cattle. There were no appreciable differences in percent of higher-priced wholesale

cuts or total trimmed retail steaks. Furthermore, the difference in percent saleable lean in the carcass between breed types was negligible. Harte (1967) observed that muscle in each cut expressed as a percentage of total carcass muscle had a remarkable similarity among Friesian, Hereford X Shorthorn and Angus X Shorthorn breeds.

Willey, Butler, Riggs, Jones and Lyerly (1951) and Stonaker, Hazaleus and Wheeler (1952) observed that "comprest" and "regular or conventional" type of Hereford steers showed appreciable similarity in the percentages of major cuts in the carcasses. This again indicated that size and form perhaps do not affect the muscle distribution in the carcass.

Exercise is known to increase the volume of skeletal muscle (Asmussen, 1968). Bull and Rusk (1942) found that exercise of cattle did not influence the cutting percentages of the carcass. Mitchell and Hamilton (1933) studied the effect of long continued muscular exercise upon chemical composition of muscles in the steer calves. In their experiment, from the chilled carcasses, the total lean from each of the nine wholesale cuts of one-half of the carcass, separated from all overlying fat by knife, was ground and sampled for chemical analyses. The percentage of water on the protoplasm basis, fat on the fresh basis and nitrogen on fat-free dry matter basis did not show any appreciable difference in the muscles from any of the nine cuts.

Butterfield (1963) compared the percentages of the total side muscles accounted for by nine anatomical groups in 54 steers of polled Hereford, Aberdeen Angus, grade Brahman, 1/2 Brahman and unimproved Shorthorn breeds. He found breed differences in only abdominal

muscles and remarkable similarity in "expensive" muscle groups. He concluded that as it will be extremely difficult to change muscle weight distribution, so some other parameters with larger variations, e.g. fertility or growth rate should be given due importance in selection. Recently, Hedrick, Stringer and Krause (1969) studied the effect of conformation grade on the yield of uniformly trimmed retail cuts from 48 average choice and 36 good conformation steer carcasses with an equal number of carcasses in each hot carcass weight groups. They recorded no significant differences in percent of retail cuts from the primal wholesale cuts or percent of thick retail cuts attributing to conformation. Cundiff, Gregory, Koch and Dickerson (1969) concluded the selection to change proportion of retail product from various wholesale cuts to total retail product would not be effective. It seems quite obvious from the present study and the literature cited that it will be extremely difficult to change the intrinsic harmony of muscle weight distribution by genetic or other environmental means. Therefore emphasis in selection might best be placed on those traits which show greater variability between breeds, e.g. rate of growth, feed efficiency and carcass composition.

(3) <u>Relative growth patterns of bovine standard anatomical muscle groups</u>

Butterfield (1963) demonstrated different growth patterns of muscle groups by comparison of percentage values for the weight of each group relative to the total muscle weight, at a series of ages from birth to maturity. The muscle groups were described as 'early developing', when the muscle group represented a higher percentage of total muscle weights at birth than later; 'average developing',

when the muscle group was uniform percentage of total muscle throughout the postnatal life; and 'late developing', when the percentage value increased following birth. In addition, a tentative classification of 'very late developing' was proposed for muscle groups whose percentage value increased in later life. From this study it was concluded that the greatest change in relative weight within the musculature occurred before the calves were six months old. This system of classification did not clearly define patterns of growth of the various groups, but stated approximately the state of growth at which maximum relative growth impetus was reached.

Butterfield and Berg (1966a) improved the method of studying the relative growth patterns of standard anatomical muscle groups relative to the total muscle in five different phases of growth between birth and 1685 days of age. The relative growth rate of standard anatomical groups over each of the five different phases was measured and interpreted through the meaning of "b" in Huxley's (1932) allometric equation of the form log Y = log A + b log X where: Y was the weight of anatomical muscle groups and X was the corresponding weight of total muscle. The magnitude of the coefficients determined the classification of relative growth pattern of a muscle group in a particular phase of development. A coefficient greater than 1.0 represented a high impetus, less than 1.0 a low growth impetus, and not different from 1.0 an average impetus. They concluded from this study that the relative growth impetus of each standard muscle group was: proximal pelvic limb, high-average or low; distal pelvic limb, low; surrounding spinal column, average; abdominal wall, high-average or high; proximal thoracic limb, low-average; distal thoracic limb,

low-average or low; thorax to thoracic limb, high; neck to thoracic limb, average-high; neck to thorax, low-average.

There is no information about influence of breed and sex on patterns of relative growth of different anatomical groups. The relative growth patterns in present study were measured through "b" values of Huxley's (1932) allometric equation holding total muscles constant to over all mean of breed or sex groups. This was done by one-way analysis of covariance.

a) Influence of breed

The growth coefficients and standard errors for each of the nine anatomical groups from different breeds of bulls, steers or heifers are shown in Table 13.

The patterns of relative growth differed significantly ($P < 0.01$) in the abdominal (Group 4) and neck and thorax (Group 9) regions among divergent breeds of bulls and steers. There was no such difference between two breed groups of heifers. The growth patterns of muscles in all other anatomical groups relative to total muscle showed a remarkable similarity among different breeds of each of three sexes as indicated by the homogeneity of slopes. These findings are in line with the results of a previous section.

The growth impetus of anatomical groups from 1 to 7 appeared to agree with that of Butterfield and Berg (1966a). The muscles in Group 8 (neck to thoracic limb) showed a higher growth impetus in most breeds of bulls and steers. This might reflect the physiological stage of muscle development in the animals involved in the present study. Different breeds of bulls also showed a high growth impetus

TABLE 13

Growth coefficients and standard errors of anatomical groups from different breeds of bulls, steers and heifers

Sex	Group No.	1	2	3	4	5	6	7	8	9
	Anatomical groups	Proximal pelvic limb	Distal pelvic limb	Surrounding spinal column	Abdominal region	Proximal thoracic limb	Distal thoracic limb	Thorax to thoracic limb	Neck to thoracic limb	Neck & thorax
	Growth impetus	High-average or low	Low	Average	High-average or high	Low-average	Low-average or low	High	Average-high	Low-average
Sex	Breed groups									
Bulls	Hereford	0.85 ± 0.08	0.98 ± 0.07	1.00 ± 0.10	0.89 ± 0.09	1.08 ± 0.09	1.10 ± 0.02	1.11 ± 0.09	1.36# ± 0.05	1.36# ± 0.03
	Hybrid	0.90 ± 0.05	0.88 ± 0.07	1.10 ± 0.05	0.98 ± 0.08	1.07 ± 0.05	0.84$ ± 0.08	1.09 ± 0.08	1.42# ± 0.06	1.01 ± 0.03
	Hybrid X Hereford	0.81 ± 0.05	0.85 ± 0.06	1.00 ± 0.01	0.54# ± 0.02	1.60# ± 0.04	1.05 ± 0.06	1.01 ± 0.02	1.34# ± 0.04	1.35# ± 0.06
	Shorthorn cross	0.84 ± 0.01	0.92 ± 0.03	0.97 ± 0.02	1.12 ± 0.05	1.00 ± 0.02	1.00$ ± 0.04	1.49# ± 0.03	1.28# ± 0.05	1.21# ± 0.06
	Holstein	0.89 ± 0.09	0.91 ± 0.07	1.04 ± 0.09	1.13 ± 0.07	0.98 ± 0.01	1.08 ± 0.09	1.13 ± 0.05	1.94# ± 0.06	1.66# ± 0.04
	Jersey	0.90 ± 0.03	0.90 ± 0.06	1.01 ± 0.02	1.32# ± 0.05	1.23# ± 0.03	1.02# ± 0.05	1.00 ± 0.02	1.67# ± 0.02	1.26# ± 0.07
	Variance ratios:									
	Between slopes	0.78	0.98	1.99	5.37**	1.31	1.21	1.46	0.93	8.47**
	Between intercepts	0.90	0.10	0.52	----	0.87	0.57	0.87	1.01	----
Steers	Hereford	0.95 ± 0.05	1.07 ± 0.04	0.94 ± 0.09	1.10 ± 0.03	0.88 ± 0.01	1.09 ± 0.07	1.03 ± 0.06	1.13 ± 0.01	1.08 ± 0.07
	Hybrid	0.93 ± 0.08	0.81 ± 0.08	1.10 ± 0.03	1.14 ± 0.01	0.93 ± 0.06	0.98 ± 0.09	0.96 ± 0.03	1.31# ± 0.04	0.96 ± 0.05
	Hereford X Hybrid	1.05 ± 0.06	1.00 ± 0.09	0.91 ± 0.08	1.17 ± 0.04	0.87 ± 0.02	1.01 ± 0.02	1.34# ± 0.05	1.38# ± 0.06	0.75$ ± 0.07
	Hybrid X Hereford	1.16 ± 0.01	1.06 ± 0.06	1.31# ± 0.09	0.85 ± 0.01	0.85 ± 0.07	1.14 ± 0.04	0.97 ± 0.05	1.22# ± 0.03	0.61# ± 0.03
	Hereford X (A.G.)	1.12 ± 0.03	0.90 ± 0.07	0.97 ± 0.09	1.00 ± 0.05	0.90 ± 0.08	0.87 ± 0.01	1.00 ± 0.06	1.14 ± 0.07	0.51# ± 0.02
	Shorthorn cross	0.90 ± 0.02	0.90 ± 0.03	1.01 ± 0.03	1.16 ± 0.05	1.00 ± 0.03	1.02$ ± 0.03	1.11 ± 0.04	1.19 ± 0.08	1.06 ± 0.03
	Brown Swiss cross	0.92 ± 0.02	1.02 ± 0.02	1.08 ± 0.07	1.15 ± 0.08	0.98 ± 0.07	0.96 ± 0.09	0.96 ± 0.07	1.18 ± 0.08	0.87 ± 0.09
	Holstein	0.94 ± 0.09	0.95 ± 0.07	1.02 ± 0.07	1.32# ± 0.04	1.05 ± 0.06	1.10 ± 0.01	1.10 ± 0.07	1.15 ± 0.07	1.16 ± 0.08
	Variance ratios:									
	Between slopes	1.68	1.04	1.91	5.12**	0.87	1.31	1.09	1.61	4.64**
	Between intercepts	1.90	0.91	1.01	----	1.20	1.61	1.76	1.66	----

continued

TABLE 13 (continued)

Growth coefficients and standard errors of anatomical groups from different breeds of bulls, steers and heifers

	Group No.	1	2	3	4	5	6	7	8	9
	Anatomical groups	Proximal pelvic limb	Distal pelvic limb	Surrounding spinal column	Abdominal region	Proximal thoracic limb	Distal thoracic limb	Thorax to thoracic limb	Neck to thoracic limb	Neck & thorax
	Growth impetus	High-average or low	Low	Average	High-average or high	Low-average	Low-average or low	High	Average-high	Low-average
Sex	Breed groups									
Heifers	Hereford	0.97 ± 0.01	1.14 ± 0.06	1.33# ± 0.04	1.20# ± 0.05	0.85 ± 0.05	1.27# ± 0.02	1.02 ± 0.03	0.73$ ± 0.06	1.08 ± 0.08
	Shorthorn cross	0.93 ± 0.04	1.05 ± 0.06	1.10 ± 0.06	1.28# ± 0.08	0.92 ± 0.04	0.83 ± 0.06	1.06 ± 0.04	1.18 ± 0.07	0.97 ± 0.05
	Variance ratios:									
	Between slopes	1.51	1.21	0.43	0.92	1.31	1.41	0.10	0.10	0.02
	Between intercepts	0.26	1.00	1.21	2.10	0.92	0.21	0.43	2.65	2.02

* Significant at ($P<0.05$).
** Significant at ($P<0.01$).
$ = significantly different from 1.00 ($P<0.05$).
# = significantly different from 1.00 ($P<0.01$).

in Group 9 (neck and thorax). This trend in Group 9 muscles does not seem to agree with that of Butterfield and Berg's (1966a) tentative classification based on steers. However, their findings were in line with other sex groups.

b) Influence of sex

Influence of sex on the relative growth patterns of nine anatomical groups was appraised in five breed groups (Table 14). The rate of relative growth of certain anatomical groups showed a definite trend in some sex comparisons. In the muscles of the proximal pelvic limb (Group 1) and abdominal region (Group 4) there was a definite trend of heifers being greater in growth coefficients over steers and steers over bulls. This trend reached a significant level in the abdominal muscles of HY and HL groups. Again, intrinsic muscles of thoracic and neck region (Groups 7, 8 and 9) showed a reverse order of sex influence with bulls being greater (non-significant) in their rates of relative growth compared with steers and steers compared with heifers.

TABLE 14

Among sex group comparisons of growth coefficients in five different breeds

Breed	Hereford			Variance ratios		Hybrid		Variance ratios		Hybrid X Hereford		Variance ratios		Shorthorn cross			Variance ratios		Holsteins		Variance ratios	
Sex group	Bulls	Steers	Heifers	Between		Bulls	Steers	Between		Bulls	Steers	Between		Bulls	Steers	Heifers	Between		Bulls	Steers	Between	
				Slopes	Intercepts			Slopes	Intercepts			Slopes	Intercepts				Slopes	Intercepts			Slopes	Intercepts
1. Proximal pelvic limb	0.85	0.95	0.97	0.45	1.31	0.90	0.93	0.12	0.60	0.81	1.16	3.36	0.78	0.84	0.90	0.93	2.58	1.94	0.89	0.94	0.06	0.13
2. Distal pelvic limb	0.98	1.07	1.14	2.08	0.10	0.88	0.81	0.03	2.25	0.85	1.06	0.58	0.17	0.92	0.90	1.05	3.30*	----	0.91	0.95	0.02	2.41
3. Surrounding spinal column	1.00	0.94	1.33	1.56	1.11	1.10	1.10	0.02	2.09	1.00	1.31	6.90*	----	0.97	1.01	1.10	2.37	1.30	1.04	1.02	3.0	0.88
4. Abdominal region	0.89	1.10	1.20	0.34	0.01	0.98	1.14	1.07	15.8**	0.54	0.85	0.71	0.34	1.12	1.16	1.28	1.45	1.20	1.13	1.32	1.98	11.4**
5. Proximal thoracic limb	1.08	0.88	0.85	2.24	1.98	1.07	0.93	1.95	0.40	1.60	0.85	34.90**	----	1.00	1.02	0.92	4.58*	----	0.98	1.05	5.3*	----
6. Distal thoracic limb	1.10	1.09	1.27	7.59**	----	0.84	0.98	0.50	2.27	1.05	1.14	0.14	2.58	1.00	0.79	0.83	3.94*	----	1.08	1.10	0.02	0.12
7. Thorax to thoracic limb	1.11	1.03	1.02	0.18	0.10	1.09	0.96	0.65	2.18	1.01	0.97	0.81	0.55	1.49	1.11	1.06	1.17	0.55	1.13	1.10	0.06	0.87
8. Neck to thoracic limb	1.36	1.13	0.73	2.70	0.17	1.42	1.31	0.67	4.52*	1.34	1.22	0.16	0.19	1.28	1.19	1.18	0.66	0.13	1.94	1.15	0.87	0.16
9. Neck and thorax	1.36	1.08	1.08	1.25	1.45	1.01	0.96	0.04	8.24**	1.35	0.61	3.37*	----	1.21	1.06	0.97	4.53*	----	1.66	1.16	0.67	0.29

* Significant at ($P < 0.05$).
** Significant at ($P < 0.01$).

C. Bone weight distribution and growth patterns of component bone

(1) Bone weight distribution in beef cattle

There is very little information available in the literature relating to factors influencing bone weight distribution in a carcass of beef. Therefore, in this part of the present study attempts were made to investigate breed or sex differences in bone weight distribution over a number of breeds and breed-crosses in cattle.

Bone weight distribution was measured by expressing component bones as percentages of total bone. Breed or sex differences in the mean percentage weights were tested by one-way analysis of variance.

a) Influence of breed

Influence of different breeds of bulls, steers or heifers on the distribution of weights for fourteen different components of bones are given in Table 15.

The cervicle vertebrae, seven in number, form the skeleton of the neck. Among breed group variation was significant ($P<0.01$ or $P<0.05$) for these bones in bulls and steers without showing such difference between two breeds of heifers.

The thoracic vertebrae, thirteen in number, form the roof of the thoracic cavity. They are also appropriately called costal vertebrae because the ribs are hinged on them. The bone weight distribution of the thoracic vertebrae did not show any significant differences among diverse breed groups of bulls, steers or heifers.

The lumbar vertebrae, six in number, form the axial skeleton of the back. A significant ($P<0.01$ or $P<0.05$) breed differences was

TABLE 15

Means and standard deviations of component bones as percentage of total bone from different breed groups of bulls, steers and heifers

Sex	Bone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Component bones	Cervicle vertebrae	Thoracic vertebrae	Lumbar vertebrae	Ribs	Sternum & rib cartilages	Scapula	Humerus	Radius & Ulna	Femur	Tibia & Fibula	Carpus	Tarsus	Patella	Hip bone
Sex	Breed groups														
Bulls	Hereford	7.3^a	8.9	5.8^c	16.5^a	6.6	5.9	8.4^c	6.2^c	11.1^c	7.0^a	1.3^c	4.1^a	0.8	10.0
	Hybrid	7.4^a	8.7	5.6^c	15.5^c	6.9	5.3	8.8^a	6.2^c	11.2^c	7.0^a	1.4^c	3.3^c	0.7	11.7
	Hybrid X Hereford	6.7^c	8.5	6.1^a	16.4^a	5.9	5.7	8.4^c	6.1^c	11.1^c	7.1^a	1.5^a	4.1^a	0.7	11.3
	Shorthorn cross	7.2^a	9.2	4.9^e	16.3^a	6.8	5.6	8.4^c	6.1^c	11.5^a	6.1^c	1.5^a	4.2^a	0.8	11.3
	Holstein	7.7^a	9.1	5.4^c	13.9^e	6.8	5.5	9.0^a	6.6^a	11.4^a	7.4^a	1.3^c	3.9^a	0.8	11.2
	Jersey	6.7^c	9.0	4.9^e	16.9^a	6.9	5.4	8.3^c	6.0^c	11.0^c	7.0^a	1.2^c	3.4^c	0.8	12.3
	Pooled standard deviations:	1.00	0.94	1.02	1.38	0.99	0.41	0.40	0.30	0.60	0.44	0.14	0.53	0.10	0.98
	Variance ratios:	4.40**	2.19	2.44*	4.68**	0.74	2.08	3.47**	3.62**	3.21**	2.43*	5.59**	5.95**	1.41	1.43
Steers	Hereford	6.9^c	8.7	5.7^a	15.1^c	6.1^e	5.8	8.8	6.4	11.8	7.3	1.7^a	3.8^c	0.8	10.6
	Hybrid	6.5^c	8.2	5.0^c	16.0^a	6.3^c	5.3	8.7	6.5	11.4	7.3	1.4^c	3.8^c	0.8	11.8
	Hereford X Hybrid	6.6^c	8.4	4.9^c	16.1^a	5.5^e	5.5	8.7	6.5	11.7	7.3	1.3^c	4.1^a	0.8	11.8
	Hybrid X Hereford	6.6^c	8.4	4.9^c	16.1^a	5.5^e	5.5	8.7	6.5	11.7	7.3	1.3^c	4.1^a	0.8	11.8
	Hereford X (A.G.)	7.4^a	8.6	5.4^a	15.4^c	5.9^e	5.4	8.6	6.3	11.2	7.1	1.3^c	4.5^a	0.8	12.1
	Shorthorn cross	7.1^a	8.6	4.8^c	15.6^c	6.5^c	5.5	8.5	6.5	11.6	7.2	1.7^a	4.1^a	0.8	11.3
	Brown Swiss cross	7.0^a	8.8	5.7^a	14.3^e	7.0^a	5.2	8.9	6.5	11.8	7.4	1.4^c	3.7^c	0.8	11.3
	Holstein	7.6^a	9.0	5.2^c	13.6^e	6.4^c	5.3	8.9	6.7	11.8	7.5	1.5^a	4.0^a	0.8	11.4
	Pooled standard deviations:	0.75	0.74	0.84	1.36	0.84	0.65	0.66	0.52	0.17	0.63	0.17	0.41	0.10	1.17
	Variance ratios:	2.51*	1.37	3.51**	3.30**	2.74**	1.17	0.76	1.48	1.07	1.28	9.64**	3.72**	1.01	1.13
Heifers	Hereford	6.8	8.6	5.6	14.7	5.7	5.3	8.8	6.7	11.9	7.7	1.0	3.5	0.9	12.4
	Shorthorn cross	6.8	8.4	4.6	14.8	6.4	5.4	8.3	6.6	11.4	7.3	1.4	4.1	0.8	12.9
	Pooled standard deviations:	0.69	1.37	0.89	1.06	0.76	0.30	0.33	0.22	0.63	0. 0.49	0.14	0.69	0.10	0.97
	Variance ratios:	1.01	0.18	8.21**	6.61*	5.68*	0.02	10.31**	1.22	3.01	5.28*	12.68**	5.34*	0.27	2.65

* Significant at ($P < 0.05$).
** Significant at ($P < 0.01$).
a c e means in the same column and sex group having different superscript differ significantly at ($P < 0.01$ or $P < 0.05$).

found in bone weight distribution of lumbar vertebrae among different breed groups of bulls, steers or heifers.

The vertebral column (sum of cervicle, thoracic and lumbar vertebrae) constituted about 20-22.2% of the total bone weight in the carcass. Among different breeds of bulls, HL had the highest proportion (22.2%) of bone in vertebral column; HE (22.0%), HY (21.7%), HY X HE (21.3%) and SH (21.3%) were intermediate in position and JR (20.6%) had the lowest proportion of bones in this part. Again, in the steer group, HL (21.9%) and BS (21.5%) had higher proportions of bone in this region compared to other breeds. HE heifers (21.2%) had more bone in the vertebral column than SH heifers (20.0%). The percentage weights of bones comprising the vertebral column seem to reflect the sizes of different breeds with heavier breeds (HL and BS) having more bones than the smaller breeds (JR and SH).

The skeleton of the thorax comprises, besides thoracic vertebrae already described, the ribs, the costal cartilages and the sternum. Together these circumscribe a cavity known as the thoracic cavity. The ribs and their cartilages form its lateral walls and the sternum its floor. There was a considerable variation ($P < 0.01$ or $P < 0.05$) in the percentage weight of ribs among different breeds of bulls, steers and heifers. HL and BS had a smaller proportion of bone in the ribs. JR bulls had significantly greater proportion of bone in this section of the skeleton. HE, HY, SH and other breed-crosses appeared to be intermediate in the percentage weights of bone in the ribs. This indicated that the larger breeds had proportionately less bone in ribs compared to the smaller breeds while the medium sized breeds occupied intermediate positions in this respect.

Sternum and rib cartilages did not show any significant difference among different breeds of bulls. However, among breed variation was significant in the other two sex groups.

The scapula or shoulder blade, a flat bone providing surface for the attachment of muscles did not seem to be appreciably affected by breed variations in any of the three sex groups.

Humerus, radius and ulna, femur and tibia and fibula are the long bones of the limbs. The special function of these bones is to bear weight. They also provide the levers necessary for locomotion. There was significant breed difference in percent humerus of bulls and heifers. Breed groups of steers did not show any appreciable variation in this bone. HL bulls and BS and HL steers had proportionately larger humeri compared with other breeds of respective sexes groups. HE heifers also had larger humeri than SH heifers.

The percentage weights of radius and ulna differed significantly ($P < 0.01$) among different breeds of bulls without showing any appreciable breed differences in steers and heifers. HL bulls contained significantly ($P < 0.01$) larger radius and ulna compared with other breeds of bulls. Although it was not statistically significant HL and BS steers were higher in percentage weight in this long bone than other breeds of steers.

The femur is the most massive long bone in the body. Among breed variation in this long bone was significant ($P < 0.01$) in bulls. Diverse breeds of steers or heifers did not show any significant difference in this bone. These findings appeared to indicate that the heavy breeds (HL and BS) contained larger long bones compared to the lighter breeds (e.g. JR and SH) indicating larger breeds needed more

massive long bones to support their larger body weight. These results are in line with the findings of Callow (1962) with respect to steers of HL, HE and SH breeds.

The carpel and tarsel bones are collections of small bones forming knee and hock joints respectively. These bones play an important role in diminishing the risk of injury from concussion. They also serve to distribute weight and pressure. There was significant breed variations in these bones in all three sexes. It is difficult to explain this breed variation on the basis of functional demands on these short bones. The patella is another short bone articulating with the trochlea of the femur. Corresponding with the knee-cap of the human subject, it is a typical sesamoid bone, its function being to give, increased lever power to the quadriceps femoris muscle. Breed differences were not present in this bone in any of the three sexes.

The hip bones did not show any significant breed differences in any of the three sexes. Callow (1962) also did not find any significant differences between HE, SH or HL steers in this bone.

b) Influence of sex

Influence of sex on bone weight distribution was appraised in five different breeds of cattle (Table 16).

Sex appeared to exert influence on all three segments (cervicle, thoracic and lumbar) of the vertebral column. In general, bulls were heavier in these parts of the axial skeleton compared with steers and steers compared with heifers. This trend of sex differences was statistically significant in the neck region of HE and HY, in the thoracic region of SH and in the lumbar region of HY X HE breeds.

TABLE 16

Among sex group comparisons of component bones as percentage of total bone in five breeds

Breed group	Hereford				Hybrid			Hybrid X Hereford			Shorthorn cross				Holstein		
Sex	Bulls	Steers	Heifers	Variance Ratios	Bulls	Steers	Variance Ratios	Bulls	Steers	Variance Ratios	Bulls	Steers	Heifers	Variance Ratios	Bulls	Steers	Variance Ratios
1. Cervicle vertebrae	7.3	6.9	6.8	14.88**	7.4	6.5	7.20**	6.7	6.6	0.01	7.2	7.1	6.8	1.58	7.7	7.6	3.16
2. Thoracic vertebrae	8.9	8.7	8.6	2.27	8.7	8.2	2.57	8.5	8.4	0.07	9.2	8.6	8.4	3.46*	9.1	9.0	0.10
3. Lumbar vertebrae	5.8	5.7	5.6	0.04	5.6	5.0	3.04	6.1	4.9	9.69**	4.9	4.8	4.6	0.36	5.4	5.2	0.20
4. Ribs	16.5	15.1	14.7	7.35**	15.5	16.0	1.00	16.4	16.1	0.21	16.3	15.6	14.8	4.49*	13.9	13.6	0.21
5. Sternum & Rib cartilages	6.6	6.1	5.7	2.25	6.9	6.3	5.75*	5.9	5.5	1.23	6.8	6.5	6.4	00.54	6.8	6.4	3.59
6. Scapula	5.9	5.8	5.3	4.76*	5.3	5.3	3.21	5.7	5.5	0.49	5.6	5.5	5.4	0.45	5.5	5.3	0.51
7. Humerus	8.4	8.8	8.8	4.06*	8.8	8.7	0.54	8.4	8.7	1.45	8.4	8.5	8.3	0.29	9.0	8.9	4.57*
8. Radius & Ulna	6.2	6.4	6.7	15.06**	6.2	6.5	9.68**	6.1	6.5	0.60	6.1	6.5	6.6	10.39**	6.6	6.7	0.10
9. Femur	11.1	11.8	11.9	7.85**	11.2	11.4	1.70	11.1	11.7	1.70	11.5	11.6	11.4	0.42	11.4	11.8	13.14**
10. Tibia & Fibula	7.0	7.3	7.7	8.23**	7.0	7.3	2.38	7.1	7.3	0.40	6.1	7.2	7.3	6.95**	7.4	7.5	0.18
11. Carpus	1.3	1.7	1.0	3.47*	1.4	1.4	0.37	1.5	1.3	8.77**	1.5	1.7	1.4	2.82	1.3	1.5	2.35*
12. Tarsus	4.1	3.8	3.5	0.17	3.3	3.8	18.48**	4.1	4.1	0.01	4.2	4.1	4.1	0.54	3.9	4.0	2.21
13. Patella	0.8	0.8	0.9	7.45**	0.7	0.8	2.67	0.7	0.8	0.46	0.8	0.8	0.8	1.46	0.8	0.8	1.10
14. Hip bone	10.0	10.6	12.4	4.80*	11.7	11.8	0.10	11.3	11.8	0.81	11.3	11.3	12.9	8.83**	11.2	11.4	3.41

* Significant at ($P < 0.05$).
** Significant at ($P < 0.01$).
Means underscored by the same line in a breed do not differ significantly at ($P < 0.01$ or $P < 0.05$).

Bulls contained proportionately more bone in the ribs over steers and steers over heifers in all breeds except that in HY. This difference was significant in HE and SH breed groups.

The trend in sternum, rib cartilage and scapula was that bulls contained a higher percentage bone in these parts, steers intermediate and heifers low. However, not all differences were significant (Table 16).

The influence of sex on percentage weights of long bones, except the humeri, showed a definite pattern with heifers having higher proportions over steers and steers over bulls. Sex differences were significant in these long bones in many comparisons (Table 16).

Among sex group variation in the proportions of carpus, tarsus and patella were also significant in some breeds. No specific conclusion could be arrived at because sex influence did not show any definite trend in these data.

In the pelvic region (hip bone) HE and SH heifers had significantly ($P<0.01$ or $P<0.05$) larger percentages of bone compared with either bulls or steers. The females possess a wider pelvic outlet compared with males to facilitate calving. So the higher proportion of bone circumscribing a larger pelvic opening appeared to be related to the reproductive functions of females.

Sex influence was thus appreciable with bulls being comparatively heavy in the percentage weights in vertebral column, ribs and sternum and rib cartilages over steers and steers over heifers. This trend was reversed in long bones of limbs and in hip bones where heifers had proportionately heavier weights.

(2) Breed and sex influence on total weights of different components of bone

In this section of the present study attempts were made to investigate breed and sex variations in adjusted mean weights of fourteen major bone components when the total bone in the side of a carcass was held to a constant level by one-way analysis of covariance.

a) Influence of breed

There was a considerable breed variation in the adjusted means of different components of bone in all three sex groups (Table 17). Although the significant differences in the percentage means of bones by one-way analysis of variance (Section 1) did not exactly coincide with the results analysed by one-way analysis covariance (Section 2), breed differences seem to show similar trends under both systems of analysis.

The larger breeds again appeared to contain more bones in the axial part of the skeleton compared with the smaller breeds while the medium sized breeds were intermediate in this respect. Thus in bull group, HL contained higher (3.47 kg) and JR had lesser (3.12 kg) bones in the vertebral column. HE (3.20 kg), HY (3.29 kg) and SH (3.28 kg) were intermediate in position. Similar trend was also found in steer groups with HL and BS having greater bone in vertebral column over the other breed groups. Between two breeds of heifers, SH contained less bone in this part than HE (2.11 vs 2.34 kg).

There was also appreciable breed differences in the bones of the ribs in all three sex groups with the smaller breed (JR) having more bones compared with larger breeds (HL and BS) while the other breeds and breed-crosses were again intermediate in this respect.

TABLE 17

Adjusted mean weights ($\overline{y}'$) for fourteen component bones in the carcass of different breeds of bulls, steers and heifers

Sex	Bone No. / Component bones / Breed groups		1 Cervicle vertebrae	2 Thoracic vertebrae	3 Lumbar vertebrae	4 Ribs	5 Sternum & rib cartilages	6 Scapula	7 Humerus	8 Radius & Ulna	9 Femur	10 Tibia & Fibula	11 Carpus	12 Tarsus	13 Patella	14 Hip bone
Bulls	Hereford	$\overline{y}'$	0.93^{c}	1.37^{a}	0.90	2.57^{a}	1.01	0.92^{a}	1.31^{c}	0.96^{c}	1.70^{c}	1.08^{c}	0.20^{c}	0.54	1.17^{a}	1.89
	Hybrid	$\overline{y}'$	1.17^{a}	1.24^{c}	0.88	2.50^{a}	0.97	0.86^{a}	1.34^{c}	0.97^{c}	1.76^{c}	1.11^{a}	0.21^{c}	0.52	1.16^{a}	1.85
	Hybrid X Hereford	$\overline{y}'$	1.04^{c}	1.28^{c}	0.97	2.50^{a}	1.12	0.85^{a}	1.30^{c}	1.01^{a}	1.75^{c}	1.12^{a}	0.25^{a}	0.60	1.18^{a}	1.76
	Shorthorn cross	$\overline{y}'$	1.10^{a}	1.44^{a}	0.74	2.52^{a}	1.05	0.88^{a}	1.31^{c}	0.95^{c}	1.74^{c}	1.05^{c}	0.25^{a}	0.60	1.15^{a}	1.79
	Holstein	$\overline{y}'$	1.24^{a}	1.40^{a}	0.83	1.99^{c}	1.00	0.80^{c}	1.39^{a}	1.03^{a}	1.91^{a}	1.14^{a}	0.21^{c}	0.62	1.29^{a}	1.91
	Jersey	$\overline{y}'$	0.99^{c}	1.39^{a}	0.74	2.67	1.00	0.92^{a}	1.27^{c}	0.93^{c}	1.65^{c}	1.09^{c}	0.19^{c}	0.35	1.03^{c}	1.87
	Variance ratios:															
	Between slopes		0.17	1.86	0.09	0.30	0.62	1.67	1.43	0.79	2.01	0.14	0.36	2.45*	0.48	0.57
	Between intercepts		4.03*	2.67*	2.01	8.67**	0.54	3.64**	3.32**	2.72*	5.05**	2.99*	4.96**	----	2.51*	1.12
Steers	Hereford	$\overline{y}'$	1.01	1.34	0.81^{c}	2.14^{a}	1.23^{a}	0.84	1.30	0.97	1.75	1.05	0.20	0.52	1.34^{a}	1.79
	Hybrid	$\overline{y}'$	0.98	1.30	0.75^{c}	2.40^{a}	1.03^{c}	0.80	1.31	0.98	1.71	1.09	0.21	0.57	1.14^{c}	1.74
	Hereford X Hybrid	$\overline{y}'$	1.04	1.34	0.79^{c}	2.33^{a}	1.02^{c}	0.83	1.34	0.97	1.76	1.09	0.21	0.60	1.19^{c}	1.65
	Hybrid X Hereford	$\overline{y}'$	0.99	1.29	0.73^{c}	2.41^{a}	0.96^{c}	0.82	1.31	0.96	1.77	1.08	0.20	0.62	1.14^{c}	1.75
	Hereford X (A.G.)	$\overline{y}'$	1.01	1.29	0.90^{a}	2.36^{a}	0.79^{e}	0.80	1.28	0.94	1.69	1.04	0.20	0.59	1.18^{c}	1.91
	Shorthorn cross	$\overline{y}'$	1.05	1.28	0.75^{c}	2.36^{a}	0.98^{c}	0.82	1.26	0.97	1.73	1.09	0.22	0.59	1.29^{a}	1.72
	Brown Swiss cross	$\overline{y}'$	1.07	1.24	0.95^{a}	1.46^{c}	1.06^{c}	0.80	1.35	1.00	1.79	1.13	0.22	0.55	1.18^{c}	1.70
	Holstein	$\overline{y}'$	1.10	1.27	0.99^{a}	1.43^{c}	1.03^{c}	0.77	1.36	1.01	1.79	1.12	0.24	0.64	1.15^{c}	1.66
	Variance ratios:															
	Between slopes		1.64	2.60*	0.81	1.01	0.80	0.23	0.81	4.42**	1.58	3.35**	2.26*	2.18*	0.74	2.59*
	Between intercepts		1.76	----	2.86**	2.36*	2.14*	0.51	1.13	----	1.07	----	----	----	3.42**	----
								0.								
Heifers	Hereford	$\overline{y}'$	0.87	0.86	0.61	1.73	0.62	0.57	0.92	0.69	1.25	0.81	0.13	0.36	0.81	1.23
	Shorthorn cross	$\overline{y}'$	0.73	0.89	0.49	1.63	0.68	0.57	0.88	0.68	1.21	0.77	0.15	0.43	0.84	1.33
	Variance ratios:															
	Between slopes		0.09	0.22	1.18	1.20	0.35	0.94	0.21	0.44	1.50	1.66	0.42	3.51	0.89	0.48
	Between intercepts		24.41**	0.16	7.77**	13.19**	3.28	0.01	9.04**	0.62	2.22	5.55*	16.66**	6.89*	0.89	5.04*

* Significant at ($P<0.05$).

** Significant at ($P<0.01$).

$\overline{y}'$ indicates dependent variable adjusted to over all mean of X(Total bone = 15.50 kg in bulls, 14.98 kg in steers, 10.63 kg in heifers).

a c e means having different superscript in a column and sex differ significantly at ($P<0.01$ or $P<0.05$).

Among breed variation reappeared in all the long bones of bulls, steers or heifers. It was worthwhile to note that larger breeds contained massive long bones compared with smaller breeds in each sex group.

There was appreciable breed differences in other parts of the skeletal system besides those mentioned above. However, no definite trend of breed influence was found in those sections of bones.

b) Influence of sex

Influence of sex on the adjusted mean weights of fourteen major bones was also studied in five different breeds (Table 18). Sex differences tended to show some definite trend in certain bones. In vertebral column, bulls contained non-significantly greater amounts of bones in all three sections over steers and steers over heifers in almost all comparisons. Similar trend was also found in ribs, sternum and rib cartilages. In contrast, sex influence did not show any definite trend in scapula and humerus. In other three long bones (radius & ulna, femur and tibia and fibula) sex influence was reverse with heifers having non-significantly larger bones compared with steers and steers compared with bulls. Three sets of composite small bones did not show any definite pattern of sex influence. Heifers had larger hip bones compared with either bulls or steers in HE and SH breeds.

The two systems of analyses did not seem to manifest the significance of sex differences to the equal extent. Sex differences appeared to be more or less decreased when compared at standard weights of bone than the conventional analyses of variance. However, the trend of sex

TABLE 18

Among sex group comparisons of adjusted means for fourteen component bones in five breeds

Breed group		Hereford			Variance ratios between		Hybrid		Variance ratios between		Hybrid X Hereford		Variance ratios between		Shorthorn cross			Variance ratios between		Holstein		Variance ratios between	
Sex		Bulls	Steers	Heifers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts	Bulls	Steers	Heifers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts
1. Cervicle	$\bar{y}'$	1.02	0.88	0.76	0.01	2.11	1.23	1.07	1.38	5.03*	1.07	1.05	0.07	0.08	0.91	0.91	0.85	0.64	2.11	1.40	1.21	2.05	3.42
2. Thoracic	$\bar{y}'$	1.19	1.12	1.10	0.53	1.50	1.42	1.36	0.21	0.12	1.36	1.34	0.99	0.07	1.17	1.09	1.05	1.35	3.57*	1.68	1.67	1.33	0.01
3. Lumbar	$\bar{y}'$	0.75	0.74	0.74	0.55	0.01	0.92	0.85	1.67	0.14	0.99	0.78	0.74	9.50**	0.62	0.62	0.61	1.02	0.19	0.98	0.95	0.13	0.11
4. Ribs	$\bar{y}'$	2.18	1.95	1.89	1.32	5.15**	2.72	2.68	1.95	0.26	2.60	2.59	0.01	0.02	2.14	1.99	1.88	0.30	17.95**	2.80	2.54	1.12	4.31
5. Sternum & Rib cartilages	$\bar{y}'$	0.87	0.78	0.72	0.87	0.82	1.13	1.04	1.09	3.58	1.02	0.96	0.80	0.62	0.85	0.83	0.82	0.49	0.25	1.24	1.17	0.78	0.37
6. Scapula	$\bar{y}'$	0.73	0.75	0.75	0.96	0.20	0.94	0.89	3.24	2.26	0.92	0.87	0.13	1.41	0.69	0.68	0.70	1.89	0.24	1.00	0.93	0.15	0.39
7. Humerus	$\bar{y}'$	1.08	1.14	1.14	0.68	3.19	1.43	1.43	2.01	1.10	1.33	1.40	1.07	2.12	1.06	1.07	1.04	0.24	0.46	1.63	1.62	0.12	0.71
8. Radius & Ulna	$\bar{y}'$	0.80	0.85	0.84	0.51	8.65**	1.03	1.08	2.45	7.13*	0.95	1.11	1.61	3.02	0.77	0.82	0.83	0.14	11.96**	1.14	1.17	1.59	3.44
9. Femur	$\bar{y}'$	1.42	1.52	1.52	0.10	2.52	1.86	1.88	1.93	0.38	1.74	1.89	1.14	0.08	1.40	1.46	1.47	2.92	3.42*	2.12	2.18	0.98	1.39
10. Tibia & Fibula	$\bar{y}'$	0.93	0.94	0.95	0.15	0.01	1.17	1.20	2.17	1.18	1.11	1.18	1.64	1.60	0.87	0.89	0.94	2.23	10.01**	1.30	1.34	0.83	2.24
11. Carpus	$\bar{y}'$	0.17	0.16	0.16	1.82	0.92	0.23	0.23	0.11	0.12	0.24	0.21	0.01	7.77**	0.20	0.21	0.17	0.24	4.93*	0.24	0.28	0.15	3.45
12. Tarsus	$\bar{y}'$	0.48	0.46	0.42	0.97	1.30	0.56	0.64	0.59	15.65**	0.66	0.66	1.88	0.03	0.56	0.54	0.46	1.26	8.69**	0.67	0.72	0.03	0.80
13. Patella	$\bar{y}'$	0.10	0.11	0.10	0.04	0.01	1.19	1.29	4.18**	----	0.12	0.12	0.07	0.79	0.10	0.10	0.94	10.67**	----	1.44	1.48	0.33	0.15
14. Hip bone	$\bar{y}'$	1.50	1.51	1.55	3.16	0.82	1.98	1.96	1.35	1.50	1.18	1.19	0.04	0.21	1.43	1.43	1.59	1.46	9.83**	2.12	2.11	0.02	11.32**

* Significant at ($P<0.05$).
** Significant at ($P<0.01$).
Means underscored by the same line do not differ significantly at ($P<0.01$ or $P<0.05$).
$\bar{y}'$ indicates dependent variable adjusted to over all mean of X(Total bone = 12.93 kg in Hereford; 16.59 kg in Hybrid; 15.98 kg in Hybrid X Hereford, 12.60 kg in Shorthorn cross and 18.25 kg in Holstein).

differences seem to follow the similar patterns under both systems of analyses.

(3) Growth coefficients of component bones in cattle

In this section of the present experiment influence of breed and sex on growth coefficients of fourteen different bones was studied. Growth coefficients were measured from "b" values of equation $\log Y = \log A + b \log X$, where Y was weight of individual bone in Kg and X was weight of total bone in kg. The growth coefficients were tested for significant differences among divergent breed groups of three sexes by one-way analysis of covariance.

a) Influence of breed

In general the patterns of growth of several component bones relative to total bone was found similar among divergent breeds of three sex groups as indicated by the homogeneity of slopes (Table 19). However, there was a considerable breed variation in the adjusted means of many bones. This appeared to indicate that the maximum differential growth of bone occurred in earlier stages of development and maintained over the period represented in the present study.

Breed size did not appear to distinctly reflect the growth impetus of bones in the axial part of the skeletons. However, the larger breeds (HL and BS) showed average to high type of impetus in this section and the smaller breeds (JR) showed average impetus. While the growth impetus of medium sized breeds (HY, SH and other breed-crosses) were mostly of average type in this section with a few high or low impetuses.

TABLE 19

Growth coefficients and standard errors of component bones from different breeds of bulls, steers or heifers

Sex	Breed groups		1 Cervicle vertebrae	2 Thoracic vertebrae	3 Lumbar vertebrae	4 Ribs	5 Sternum & Rib cartilages	6 Scapula	7 Humerus	8 Radius & Ulna	9 Femur	10 Tibia & Fibula	11 Carpus	12 Tarsus	13 Patella	14 Hip bone
Bulls	Hereford	b±S.E.	1.01 ±0.05^{a}	1.39#±0.05	1.73#±0.01	1.06 ±0.05^{e}	1.71#±0.02	1.45#±0.03^{a}	1.12 ±0.03^{a}	1.07 ±0.01^{c}	0.98 ±0.07^{a}	0.77 ±0.03^{c}	1.01 ±0.09^{a}	0.45#±0.02	0.84 ±0.04^{c}	0.89 ±0.01
	Hybrid	b±S.E.	1.06 ±0.05^{a}	0.92 ±0.03	1.43#±0.03	1.20 ±0.02^{c}	1.14 ±0.04	1.32#±0.06^{a}	1.00 ±0.01^{c}	1.09 ±0.01^{c}	0.83 ±0.09^{c}	0.75 ±0.07^{c}	0.99 ±0.08^{c}	1.10 ±0.02	0.87 ±0.09^{c}	0.84 ±0.05
	Hybrid X Hereford	b±S.E.	0.84 ±0.09^{c}	1.10 ±0.05	1.14 ±0.05	1.23 ±0.02^{c}	0.86 ±0.01	0.72 ±0.08^{c}	1.02 ±0.06^{c}	0.74 ±0.05^{e}	1.03 ±0.02^{a}	0.96 ±0.05^{a}	0.89 ±0.06^{c}	1.73#±0.09	1.13 ±0.02^{a}	1.29#±0.06
	Shorthorn cross	b±S.E.	0.95 ±0.01^{c}	1.04 ±0.01	1.62#±0.08	1.35#±0.08^{c}	1.12 ±0.07	1.26 ±0.08^{a}	1.04 ±0.08^{c}	0.94 ±0.09^{c}	0.76 ±0.09^{c}	0.70 ±0.08^{c}	0.72 ±0.03^{e}	0.33#±0.02	0.65#±0.04^{e}	1.06 ±0.01
	Holstein	b±S.E.	1.03 ±0.06^{a}	2.03#±0.03	0.76 ±1.07	1.01 ±0.04^{e}	0.91 ±0.04	1.15 ±0.03^{a}	1.15 ±0.02^{a}	1.33#±0.05^{a}	1.02 ±0.08^{a}	1.00 ±0.02^{a}	0.60$±0.09^{e}	0.52#±0.05	0.60#±0.04^{e}	0.86 ±0.01
	Jersey	b±S.E.	0.83 ±0.07^{c}	1.06 ±0.07	0.73 ±0.09	1.88#±0.05^{a}	1.01 ±0.08	1.11 ±0.03^{a}	0.97 ±0.08^{c}	0.70 ±0.06^{e}	0.81 ±0.03^{c}	0.68 ±0.07^{c}	1.18 ±0.09^{a}	0.85 ±0.01	1.12 ±0.09^{a}	1.02 ±0.06
	Variance ratios:															
	Between slopes		0.05	1.02	0.23	0.56	0.57	1.26	1.46	0.82	2.29	0.26	0.43	2.61*	0.45	0.69
	Between intercepts		3.61**	2.26	1.96	6.96**	0.62	3.10*	3.42**	3.02*	4.17**	2.36*	6.78*	----	2.89*	1.70
Steers	Hereford	b±S.E.	0.78 ±0.01^{a}	1.23 ±0.02	0.89 ±0.03^{c}	0.95 ±0.09	1.22 ±0.03^{a}	1.17 ±0.05	1.10 ±0.03	0.96 ±0.01	0.99 ±0.02	0.79 ±0.05	1.39#±0.03^{a}	0.83 ±0.02^{c}	0.83 ±0.09^{c}	1.20 ±0.08
	Hybrid	b±S.E.	0.74 ±0.04^{a}	0.82 ±0.05	0.83 ±0.01^{c}	1.01 ±0.06	0.93 ±0.04^{c}	0.85 ±0.05	0.74 ±0.08	0.89 ±0.07	1.05 ±0.01	1.02 ±0.05	0.83 ±0.07^{c}	1.08 ±0.06^{a}	1.43#±0.03^{a}	1.25 ±0.08
	Hereford X Hybrid	b±S.E.	0.28#±0.05^{c}	1.37#±0.07	0.60$±0.05^{e}	0.97 ±0.02	1.59#±0.04^{a}	0.98 ±0.05	0.66$±0.08	0.93 ±0.02	0.83 ±0.03	0.68$±0.09	1.74#±0.06^{a}	1.13 ±0.06^{a}	0.85 ±0.04^{c}	1.54#±0.06
	Hybrid X Hereford	b±S.E.	0.82 ±0.02^{a}	0.55#±0.09	0.83 ±0.01^{c}	1.04 ±0.09	0.80 ±0.08^{c}	0.58$±0.01	0.99 ±0.07	0.57#±0.02	1.05 ±0.01	1.02 ±0.02	1.01 ±0.07^{a}	1.05 ±0.07^{a}	1.05 ±0.03^{a}	1.29#±0.03
	Hereford X (A.G.)	b±S.E.	0.83 ±0.03^{a}	1.19 ±0.01	0.71 ±0.08^{e}	1.06 ±0.03	1.13 ±0.01^{a}	0.67$±0.05	0.65$±0.02	0.57#±0.07	1.08 ±0.09	0.53#±0.06	1.33#±0.01^{a}	0.78 ±0.02^{c}	1.39#±0.06^{a}	2.26#±0.05
	Shorthorn cross	b±S.E.	0.87 ±0.01^{a}	0.96 ±0.01	1.22 ±0.02^{a}	1.34#±0.01	1.09 ±0.09^{a}	1.02 ±0.09	0.97 ±0.09	0.92 ±0.04	0.76 ±0.06	0.88 ±0.05	0.72 ±0.05^{c}	0.52#±0.01^{c}	1.26 ±0.01^{a}	1.07 ±0.07
	Brown Swiss cross	b±S.E.	0.77 ±0.03a	1.47#±0.08	0.88 ±0.09^{c}	0.93 ±0.01	0.92 ±0.07^{c}	1.05 ±0.01	1.12 ±0.06	0.97 ±0.06	1.10 ±0.01	1.03 ±0.07	0.74 ±0.01^{c}	0.72 ±0.09^{c}	0.76 ±0.06^{c}	0.89 ±0.03
	Holstein	b±S.E.	0.86 ±0.03^{a}	1.41#±0.06	0.70 ±0.09^{e}	0.91 ±0.07	0.83 ±0.08	1.01 ±0.05	1.10 ±0.02	1.15 ±0.06	1.12 ±0.08	1.05 ±0.07	0.83 ±0.02^{c}	0.68 ±0.09^{c}	0.76 ±0.06^{c}	0.99 ±0.01
	Variance ratios:															
	Between slopes		1.04	1.94	0.60	2.13*	0.83	0.02	0.52	4.01**	0.89	1.21	0.89	1.36	0.59	1.82
	Between intercepts		2.30*	1.33	3.35**	----	2.10*	0.45	0.73	----	1.08	1.02	2.60*	2.41*	3.82**	1.74
Heifers	Hereford	b±S.E.	0.74 ±0.23	0.81 ±0.09	0.69 ±0.09	0.55#±0.03	0.99 ±0.02	1.11 ±0.01	0.90 ±0.03	0.95 ±0.06	0.99 ±0.04	0.81 ±0.08	0.66$±0.03	1.21#±0.05	0.90 ±0.02	1.52#±0.03
	Shorthorn cross	b±S.E.	0.81 ±0.18	0.88 ±0.04	1.11 ±0.04	1.32#±0.09	1.28#±0.02	0.86 ±0.09	0.86 ±0.05	0.89 ±0.07	0.92 ±0.07	0.89 ±0.06	0.55#±0.02	1.50#±0.03	0.60$±0.02	1.19#±0.01
	Variance ratios:															
	Between slopes		0.01	0.18	2.25	6.55**	0.02	0.54	0.06	0.36	0.88	0.48	0.03	4.06	0.98	1.74
	Between intercepts		19.92**	0.44	10.20**	----	4.34*	0.02	8.77**	0.60	1.88	4.56*	18.58**	6.83*	1.44	6.02*

* Significant at ($P<0.05$).
** Significant at ($P<0.01$).
$ Significantly different from 1.00 ($P<0.05$).
\# Significantly different from 1.00 ($P<0.01$).
a c e means in a column and sex group having different superscript differ significantly at ($P<0.01$ to $P<0.05$).

b) Influence of sex

Influence of sex on growth coefficients of fourteen major bones was studied in five different breeds (Table 20). Within a breed different sexes showed some distinct trends in these constants of certain bones. In the bones of the vertebral column, the coefficients were greater in bulls over steers and in steers over heifers. This trend was not significant in most sex comparisons. Similar trend of sex influence was also found in ribs.

There was no consistency of sex influence in the bones of sternum and rib cartilages. In scapula, humerus and radius & ulna, bulls were again higher in the growth constants compared with steers and steers over heifers. This trend did not reach a level of statistical significance in any sex comparisons.

Influence of sex on the growth coefficients of three small bones did not show any definite trend. However, heifers had non-significantly larger growth coefficients for the hip bone compared with either bulls or steers in HE and SH breeds.

TABLE 20

Among sex group comparisons of growth coefficients of components of bones in five breeds

			Hereford			Variance ratios between		Hybrid		Variance ratios between		Hybrid X Hereford		Variance ratioa between		Shorthorn cross			Variance ratios between		Holstein		Variance ratios between	
			Bulls	Steers	Heifers	Slopes	Intercepts	Bulls	Steera	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepta	Bulls	Steers	Heifers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts
1.	Cervicle vertebrae	b	1.01	0.78	0.74	0.04	1.33	1.06	0.74	0.59	8.03*	0.84	0.82	0.01	0.02	0.95	0.87	0.81	0.28	2.66	1.03	0.86	1.65	3.46
2.	Thoracic vertebrae	b	1.39	1.23	0.81	0.31	1.46	0.92	0.82	0.08	1.46	1.10	0.55	0.86	0.01	1.04	0.96	0.88	0.51	3.77	2.03	1.41	0.74	0.01
3.	Lumbar vertebrae	b	1.73	0.89	0.69	0.70	0.01	1.43	0.83	1.29	2.23	1.14	0.83	1.18	8.05*	1.62	1.22	1.11	0.89	0.22	0.76	0.70	0.01	0.16
4.	Ribs	b	1.06	0.95	0.55	0.85	1.91	1.20	1.01	0.50	0.27	1.23	1.04	0.22	0.39	1.35	1.34	1.32	0.02	1.92	1.01	0.91	0.46	4.64
5.	Sternum & Rib cartilages	b	1.71	1.22	0.99	1.57	0.51	1.14	0.93	1.45	3.93	0.86	0.80	0.38	0.58	1.12	1.09	1.28	0.22	0.26	0.91	0.83	0.15	0.62
6.	Scapula	b	1.45	1.17	1.11	0.64	0.35	1.32	0.85	1.61	1.77	0.72	0.58	0.09	1.67	1.26	1.02	0.86	1.65	0.26	1.15	1.01	0.92	0.41
7.	Humerus	b	1.12	1.10	0.90	0.86	2.70	1.00	0.74	6.42**	----	1.02	0.99	2.53	1.87	1.04	0.97	0.86	0.28	0.10	1.15	1.10	0.62	1.93
8.	Radius & Ulna	b	1.07	0.96	0.95	1.27	1.84	1.09	0.89	2.74	7.44**	0.74	0.57	1.12	2.58	0 94	0.92	0.89	0.15	1.62	1.33	1.15	0.65	3.73
9.	Femur	b	0.98	0.99	0.99	0.03	2.28	0.83	1.05	2.38	0.64	1.03	1.05	0.02	2.91	0.76	0.76	0.92	2.23	2.92	1.02	1.12	0.99	1.51
10.	Tibia & Fibula	b	0.77	0.79	0.81	0.01	0.10	0.75	1.02	2.39	1.14	0.96	1.02	0.76	1.18	0.70	0.88	0.89	2.46	1.45	1.00	1.05	0.48	0.20
11.	Carpus	b	1.01	1.39	0.66	2.51	1.17	0.99	0.83	0.43	0.09	0.89	1.01	1.10	7.11*	0.72	0.72	0.55	0.43	1.19	0.60	0.83	0 08	5.86*
12.	Tarsus	b	0.45	0.83	1.21	1.01	0.62	1.10	1.08	0.01	17.75**	1.73	1.05	1.50	0.06	0.33	0.52	1.50	1.52	1.75	0.52	0.68	0.02	0.81
13.	Patella	b	0.84	0.83	0.90	0.02	1.38	0.87	1.43	3.58	3.30	1.13	1.05	0.02	0.41	0.65	1.26	0.60	9.92**	----	0.60	0.76	0.27	0.16
14.	Hip bone	b	0.89	1.20	1.52	4.05*	----	0.84	1.25	1.18	0.06	1.29	1.29	0.01	1.15	1.06	1.07	1.19	0.46	1.45	0.86	0.99	0.12	13.80**

* Significant at ($P < 0.05$).
** Significant at ($P < 0.01$).

D. Distribution and growth patterns of fatty tissue components

(1) Distribution of fatty tissue in beef cattle

Pomeroy (1960) quoted "dairy cattle fatten from the inside out whereas beef cattle fatten from outside in", in the paper where he discussed the importance and implication of anatomical distribution of edible tissues in beef cattle. There was no evidence to substantiate his convictions until Callow (1961) found out that the major difference between dairy breeds and beef breeds was the manner in which fat was distributed. He observed that Hereford steers contained a higher proportion of subcutaneous and a lower proportion of perinephric (kidney) fat than Holsteins while Shorthorns occupied an intermediate position. In a foregoing chapter of the present study, it was shown that muscle weight distribution was similar among breed groups differing in conformation and type. So it was thought that selection for conformation might have caused a shift in the distribution of fat. With this idea, and the information obtained from Callow's (1961) publication, the present study was directed to find the influence of breed and sex on the distribution of fat in the carcass. The total fat was subdivided into three major components according to the anatomical locations in the body i.e. subcutaneous, intermuscular and internal or body cavity fat. Fatty tissue distribution was measured by expressing the three components as percentages of total fats.

a) Influence of breed

The influence of different breeds of bulls, steers or heifers on three major components of fat, their mean percentages and ratios are shown in Table 21.

TABLE 21

Fatty tissue distribution among different breeds of bulls, steers and heifers

Sex	Breed group	Subcutaneous fat (kg)	Intermuscular fat (kg)	Body cavity fat (kg)	Subcutaneous fat (%)	Intermuscular fat (%)	Body cavity fat (%)	Subcutaneous: intermuscular fat ratios	Subcutaneous: body cavity fat ratios	Intermuscular body cavity fat ratios
Bulls	Hereford	18.38^{a}	14.41^{a}	3.87^{c}	51.05^{a}	38.58^{c}	10.38^{e}	1.40^{a}	5.08^{a}	3.78^{c}
	Hybrid	14.66^{c}	11.85^{c}	3.65^{c}	49.72^{a}	38.22^{c}	12.07^{e}	1.37^{a}	4.42^{c}	3.42^{c}
	Hybrid X Hereford	17.27^{a}	15.50^{a}	3.13^{e}	47.92^{a}	43.09^{a}	8.99^{d}	1.13^{c}	5.44^{a}	4.95^{a}
	Shorthorn cross	9.99^{e}	10.86^{c}	2.98^{e}	41.30^{c}	46.04^{a}	12.66^{e}	0.95^{e}	3.38^{d}	3.84^{c}
	Holstein	4.57^{d}	6.82^{d}	3.51^{c}	31.25^{e}	46.59^{a}	22.17^{c}	0.69^{d}	1.88^{e}	2.93^{d}
	Jersey	3.98^{d}	4.08^{e}	5.75^{a}	29.43^{e}	29.56^{e}	41.00^{a}	1.00^{e}	0.73^{f}	0.73^{e}
	Pooled standard deviations:	4.10	4.36	1.72	6.23	7.07	5.52	0.39	1.11	1.18
	Variance ratios:	21.33**	8.27**	2.82*	22.31**	7.13**	41.64**	5.46**	23.63**	10.64**
Steers	Hereford	16.01^{a}	13.03^{e}	2.72^{e}	50.28^{a}	41.80^{d}	7.92^{d}	1.22^{a}	7.04^{a}	6.02^{a}
	Hybrid	17.37^{a}	20.06^{a}	4.57^{c}	40.51^{e}	48.40^{c}	11.09^{c}	0.85^{c}	3.93^{c}	4.64^{c}
	Hereford X Hybrid	12.33^{c}	15.29^{c}	3.49^{c}	40.51^{e}	48.41^{c}	11.08^{c}	0.86^{c}	3.81^{c}	4.53^{c}
	Hybrid X Hereford	18.18^{a}	18.35^{a}	3.92^{c}	44.34^{c}	45.80^{e}	9.87^{e}	1.00^{a}	4.61^{c}	4.71^{c}
	Hereford X (A.G.)	18.04^{a}	16.69^{c}	3.98^{c}	46.01^{c}	43.59^{d}	10.40^{e}	1.07^{a}	4.54^{c}	4.29^{c}
	Shorthorn cross	13.11^{c}	13.78^{e}	3.73^{c}	41.79^{e}	45.68^{e}	12.53^{c}	0.93^{a}	3.56^{c}	3.80^{e}
	Brown Swiss cross	12.10^{c}	14.66^{e}	4.17^{c}	38.76^{e}	47.41^{c}	13.83^{c}	0.83^{c}	2.97^{e}	3.69^{e}
	Holstein	8.18^{e}	15.84^{c}	7.72^{a}	26.42^{d}	50.43^{a}	23.16^{a}	0.52^{e}	1.25^{d}	2.37^{d}
	Pooled standard deviations:	4.87	3.74	1.57	4.93	4.80	3.08	0.20	1.20	1.20
	Variance ratios:	5.53**	6.04**	6.42**	15.92**	3.44**	16.63**	9.16**	17.30**	6.96**
Heifers	Hereford	13.34	10.57	1.94	51.55	40.95	7.50	1.33	7.16	5.73
	Shorthorn cross	14.45	13.30	3.31	44.72	44.14	11.14	1.04	4.21	4.08
	Pooled standard deviations:	5.18	3.43	0.81	6.36	5.87	1.94	0.40	1.59	1.45
	Variance ratios:	0.25	3.46	15.50**	6.30*	1.61	19.11**	2.97	18.74**	7.09*

* Significant at ($P<0.05$).
** Significant at ($P<0.01$).
a c d e f means having different superscript in same sex group and column differ significantly at ($P<0.01$ or $P<0.05$).

There were significant ($P < 0.01$) differences in the total amount of subcutaneous, intermuscular and body cavity fat among different breed groups of bulls and steers. The two breeds of heifers did not show any significant difference in total subcutaneous and intermuscular fat although SH heifers had significantly ($P < 0.01$) greater body cavity fat than HE heifers. These differences relate to differences in total fat discussed in an earlier section and are not directly interpretable.

Breed influence on distribution can perhaps best be assessed by looking at the percentages in each depot (Table 21). Among breed group variation was significant ($P < 0.01$) in bulls and steers in the proportions of subcutaneous, intermuscular and body cavity fat. The two breeds of heifers showed appreciable ($P < 0.01$ or $P < 0.05$) difference in the proportions of subcutaneous and body cavity with no difference in the intermuscular region.

HE contained significantly ($P < 0.01$ or $P < 0.05$) greater proportions of subcutaneous fat in all three sexes. The dairy bulls (HL and JR) had the lowest ($P < 0.01$ or $P < 0.05$) percentages of subcutaneous fat compared with other breeds of bulls. Dairy steers also showed a similar trend in this trait. HY, SH and other beef-crosses were intermediate in position. Percentage of body cavity fat was very high in JR bulls followed by HL bulls. HL steers were highest in body cavity fat percentage.

Distribution of fat can also be appraised by looking at ratios among the various depots (Table 21). Subcutaneous:intermuscular fat ratio differed significantly ($P < 0.01$) among different breeds of bulls and steers. However, two breeds of heifers did not show any difference in this ratio. This ratio was highest in HE in all three sex

groups. Dairy breeds tended to be comparatively very low in this ratio. SH, HY and other beef-crosses occupied intermediate positions.

The ratio of subcutaneous to intermuscular fat was related to the degree of selection for beef characteristics by Callow (1961). However, Ledger (1959) suggested that this ratio represented animal response of adaptation to environmental temperature. Of the breeds involved in the present study, HE represents the greatest degree of selection for beef conformation. Thus these data would support Callow's contention in that selection for meatiness on the basis of conformation or type has definitely caused an increase of subcutaneous fat relative to other depots.

Breed influence on subcutaneous:body cavity and intermuscular:body cavity fat ratios were also studied (Table 21). HE and other beef-crosses were high in this ratio compared with dairy breeds in both bulls and steers. This supports further the concept that selection for conformation resulted in more fat in subcutaneous positions. On the other hand, the magnitude of these ratios were very small in dairy breeds indicating more fat in the body cavity.

These results, in essence, indicate that selection for beef type caused a shifting of fat from inside of the body to outside. An alternate explanation might be that selection for dairy type changed the fat distribution in the opposite direction i.e. from outside to inside. This hypothesis could further be supported from the work of Butterfield (1965) who showed that Brahman and polled Hereford contained more subcutaneous fat because these breeds were perhaps more heavily selected for meat qualities than Angus or Shorthorn which in turn have been more heavily selected than the Northern Territory Shorthorns

(in the Northern Territory of Australia, there are properties on which cattle have developed by 'survival of the fittest' for at least 70 years). Harte also (1967) found that subcutaneous fatty tissue was, on the average, lower in Friesians (70%) than in Herefords (78%) and lower in Herefords than in the Aberdeen Angus (80%).

b) Influence of sex

The influence of sex on total and proportion of fat and their ratios are given in Table 22. Total weight of fat in each depot is not directly interpretable because of liveweight differences at slaughter and these are included merely for information.

Proportions of fatty tissues did not follow any definite trend in sex comparisons over different breed groups. However, in the HY group, bulls contained proportionally more ($P < 0.01$) subcutaneous fat than steers and steers had more ($P < 0.01$) internal fat than bulls. HE bulls also contained a higher proportion ($P < 0.01$) of body cavity fat than the other two sexes. Sex differences were not significant in any other comparisons of proportions of fat in the three depots.

Sex influences on ratios among the fat depots were also not very pronounced (Table 22). Bulls showed a tendency of being high in subcutaneous:intermuscular fat over steers or heifers, but again this was not found in the SH group. Heifers appeared to be high in subcutaneous:body cavity fat ratio in HE and, though not significantly, in SH breeds. Bulls were non-significantly high in this ratio compared with steers in HY, HY X HE and HL groups. Sex difference in intermuscular:body cavity fat ratio did not show any pattern although it reached significance in the HE and HY groups.

TABLE 22

Among sex group comparisons of fatty tissue distribution in five different breeds

Breed groups	Hereford				Hybrid			Hybrid X Hereford			Shorthorn cross				Holstein		
Sex	Bulls	Steers	Heifers	Variance ratios	Bulls	Steers	Variance ratios	Bulls	Steers	Variance ratios	Bulls	Steers	Heifers	Variance ratios	Bulls	Steers	Variance ratios
Subcutaneous fat (kg)	18.38	16.01	13.34	3.71*	14.66	17.37	2.73	17.27	18.18	0.10	9.99	13.11	14.45	1.92	4.57	8.19	91.56**
Intermuscular fat (kg)	14.41	13.03	10.57	2.91	11.85	20.06	27.34**	15.50	18.35	1.49	10.86	13.78	13.30	1.88	6.82	15.84	61.79**
Body cavity fat (kg)	3.87	2.72	1.94	4.76*	3.65	4.57	3.87	3.13	3.92	4.65*	2.98	3.73	3.31	1.65	3.51	7.72	4.55*
Subcutaneous fat (%)	51.04	50.28	51.55	0.13	49.73	40.52	18.13**	47.92	44.33	1.57	41.30	41.79	44.72	1.16	31.25	26.42	4.05
Intermuscular fat (%)	38.58	41.80	40.95	0.92	38.22	48.40	24.29**	43.09	45.80	0.97	46.04	45.68	44.14	0.41	46.59	50.43	0.69
Body cavity fat (%)	10.38	7.92	7.50	6.00**	12.07	11.09	1.05	8.99	9.87	1.57	12.66	12.53	11.14	1.26	22.17	23.16	0.02
Subcutaneous: intermuscular fat ratios	1.40	1.22	1.33	0.46	1.37	0.85	19.61**	1.13	1.00	1.11	0.95	0.93	1.04	0.71	0.69	0.52	9.03**
Subcutaneous: body cavity fat ratios	5.08	7.04	7.16	5.14*	4.42	3.93	0.97	5.44	4.61	2.61	3.38	3.56	4.21	0.14	1.88	1.25	2.50
Intermuscular: body cavity fat ratios	3.78	6.02	5.73	5.86**	3.42	4.64	6.02*	4.95	4.71	0.29	3.84	3.80	4.09	0.37	2.93	2.37	0.58

* Significant at ($P < 0.05$).
** Significant at ($P < 0.01$)
Means underscored by the same line in a breed do not differ significantly at ($P < 0.01$ or $P < 0.05$).

In conclusion the present study indicated that there was a marked breed variation in fatty tissue distribution. HE had more subcutaneous and intermuscular fat and less body cavity fat. Dairy cattle showed an exactly opposite trend in fatty tissue distribution. HY, SH and other crossbreeds were intermediate in position in this respect. Sex differences, on the other hand, were not marked nor consistent with respect to fat distribution.

(2) Breed and sex influence on total weights of three major component of fats

Breed and sex groups differed in the total weight of fat dissected from the carcass. Therefore an attempt was made to compare these groups by statistically adjusting fat in each depot to equal amounts of total fat by one-way analyses of covariance.

a) Influence of breed

Adjusted means of three major components of fatty tissues from different breed groups of bulls, steers or heifers are given in Table 23. There was considerable breed variation in the patterns of fatty tissue deposition in all three anatomical locations among diverse breeds of bulls and steers as indicated by the heterogeneous nature of slopes. The regressions of depot fat on total fat were found to be similar for the two breeds of heifers.

It was not legitimate to test for significant differences in adjusted means from different breeds of bulls and steers. Between two breeds of heifers the HE was significantly higher in subcutaneous fat and lower in internal fat compared with the SH. This confirms the findings based on percentages in the previous section.

TABLE 23

Adjusted mean weights ($\overline{y}'$) for three major component fatty tissues in different breeds of bulls, steers and heifers

Sex	Breed group (Component fats)		Subcutaneous fat	Intermuscular fat	Body cavity fat
Bulls	Hereford	$\overline{y}'$	14.00	9.95	1.94
	Hybrid	$\overline{y}'$	13.56	10.31	3.20
	Hybrid X Hereford	$\overline{y}'$	12.88	11.39	2.65
	Shorthorn cross	$\overline{y}'$	11.37	12.16	3.36
	Holstein	$\overline{y}'$	4.52	12.14	5.05
	Jersey	$\overline{y}'$	6.42	9.88	7.44
	Variance ratios:				
	Between slopes		2.83*	4.24**	12.87**
	Between intercepts		----	----	----
Steers	Hereford	$\overline{y}'$	17.76	13.83	3.49
	Hybrid	$\overline{y}'$	13.72	17.40	3.96
	Hereford X Hybrid	$\overline{y}'$	13.25	17.83	3.99
	Hybrid X Hereford	$\overline{y}'$	15.17	16.29	3.62
	Hereford X (A.G.)	$\overline{y}'$	15.77	15.58	3.72
	Shorthorn cross	$\overline{y}'$	15.44	15.51	4.13
	Brown Swiss cross	$\overline{y}'$	14.03	16.57	4.47
	Holstein	$\overline{y}'$	8.48	16.99	9.60
	Variance ratios:				
	Between slopes		5.96**	2.63*	13.29**
	Between intercepts		----	----	----
Heifers	Hereford	$\overline{y}'$	14.94	11.58	2.17
	Shorthorn cross	$\overline{y}'$	13.11	12.46	3.12
	Variance ratios:				
	Between slopes		0.02	0.09	0.31
	Between intercepts		8.40**	1.91	25.90**

* Significant at ($P<0.05$).
** Significant at ($P<0.01$).
$\overline{y}'$ indicates dependent variable adjusted to over all mean of X(Total fat = 26.74 kg in bulls; 35.07 kg in steers and 28.69 kg in heifers).

b) Influence of sex

Sex influences on the adjusted means of three components of fatty tissue are shown in Table 24. The patterns of subcutaneous fatty tissues deposition was similar in all sex comparisons except in HY as indicated by non-significant differences in slopes. With homogeneous slopes it was possible to test for differences in adjusted means of the fat depots. HL bulls had less subcutaneous fat than steers when adjusted to an equal level of total fat. No other groups showed sex differences in adjusted subcutaneous fat means.

The relative rate of fattening in the intermuscular region was appreciably different among different sexes of HE and HY (Table 24). Homogeneous slopes were found in other sex within breed group comparisons. Among the legitimate comparisons of adjusted subcutaneous fat means, only the HL breed significant sex differences with bulls having less fat in this region than steers.

Heterogeneous rates of deposition of body cavity fat relative to total fat were observed among sexes of the HE breed while all other sex within breed comparisons indicated homogeneity. The adjusted means for body cavity fat were less for HY X HE bulls than steers but greater for HL bulls than steers while sexes showed no differences in other comparisons.

Breeds showed considerable heterogeneity in rate of fat deposition in various depots relative to total fat. Therefore the technique of adjusting depot fat to standard total fat weights could not be applied and no further interpretations of breed effects were possible. As in the comparison of percentages in the various fat depots among

TABLE 24

Among sex group comparisons of adjusted means for three major component fatty tissues in five breeds

Breed groups		Hereford			Variance ratios between		Hybrid		Variance ratios between		Hybrid X Hereford		Variance ratios between		Shorthorn cross			Variance ratios between		Holstein		Variance ratios between	
Sex		Bulls	Steers	Heifers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts	Bulls	Steers	Heifers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts
Subcutaneous fat	$\overline{y}'$	16.16	16.07	16.15	0.73	0.01	16.50	14.16	10.59**	----	19.11	17.60	0.74	2.20	12.68	112.24	13.35	1.37	2.38	5.14	7.42	0.72	11.99**
Intermuscular fat	$\overline{y}'$	12.33	13.07	12.23	3.30*	----	15.00	17.71	6.46*	----	16.92	17.90	0.59	0.84	12.83	13.14	12.49	0.75	1.12	9.01	12.92	1.96	5.35*
Body cavity fat	$\overline{y}'$	3.15	2.74	2.86	7.52**	----	4.24	3.94	1.32	0.60	3.33	3.86	0.04	5.40*	3.45	3.58	3.12	0.80	1.83	7.96	1.78	1.80	7.98*

* Significant at ($P<0.05$).
** Significant at ($P<0.01$).
$\overline{y}'$ indicates dependent variable adjusted to over all mean of X(Total fat = 31.89 kg in Hereford; 35.90 kg in Hybrid; 39.36 kg in Hybrid X Hereford; 23.96 kg in Shorthorn cross and 22.11 kg in Holstein).

sexes, adjusting to a standard total fat weight did not disclose any pattern of sex differences in fat distribution.

(3) Growth coefficients of subcutaneous, intermuscular and body cavity fat in cattle

The growth coefficients of subcutaneous, intermuscular and body cavity fat were calculated among different breeds of bulls, steers or heifers by relating these three components to total fat on a double logarithmic scale. These coefficients were also tested for significant differences from 1.00 as well as for significant differences among breed or sex groups by one-way analysis of covariance.

a) Influence of breed

There were significant breed differences in the patterns of rate of fattening among different breeds of bulls and steers as indicated by the heterogeneity of slopes (Table 25). There was no such difference between two breeds of heifers. The heterogeneity of the growth coefficients among breeds of bulls and steers for all fat depots could be interpreted as reflecting differences in relative rate of fat deposition in the various depots among breeds. With small numbers in each group, individual variability could also contribute to variability in the coefficients. The only interpretation which might be valid seems to be that growth coefficients for subcutaneous fat were low and those for body cavity fat high in dairy bulls and steers. There might have been a tendency for higher coefficients for subcutaneous than intermuscular fat in steers of the beef breeds. There was less difference between coefficients from the two depots in beef breed bulls.

Between the two heifer groups the growth coefficients were homogeneous, within all fat depots. Significant differences between

TABLE 25

Growth coefficients and standard errors of component fat in bulls, steers and heifers

Sex	Component fat / Breed group		Subcutaneous fat	Intermuscular fat	Body cavity fat
Bulls	Hereford	b±S.E.	1.08 ± 0.10	0.75 ± 0.15	0.56 ± 0.13
	Hybrid	b±S.E.	1.05 ± 0.10	0.91 ± 0.13	0.88 ± 0.25
	Hybrid X Hereford	b±S.E.	1.06 ± 0.12	0.99 ± 0.18	0.70 ± 0.22
	Shorthorn cross	b±S.E.	1.07 ± 0.13	0.98 ± 0.13	0.97 ± 0.15
	Holstein	b±S.E.	0.36# ± 0.09	0.32# ± 0.06	3.54# ± 0.09
	Jersey	b±S.E.	0.76 ± 0.17	0.98 ± 0.14	1.18$ ± 0.04
	Variance ratios:				
	Between slopes		3.62**	3.10*	3.43**
	Between intercepts		----	----	----
Steers	Hereford	b±S.E.	1.34# ± 0.01	0.62$ ± 0.03	0.63 ± 0.29
	Hybrid	b±S.E.	1.30# ± 0.11	0.83 ± 0.08	0.74 ± 0.22
	Hereford X Hybrid	b±S.E.	1.19 ± 0.06	0.85 ± 0.01	0.83 ± 0.29
	Hybrid X Hereford	b±S.E.	1.31# ± 0.04	0.79 ± 0.13	0.61 ± 0.13
	Hereford X (A.G.)	b±S.E.	1.06 ± 0.10	0.72 ± 0.11	0.73 ± 0.20
	Shorthorn cross	b±S.E.	1.22# ± 0.07	0.87 ± 0.05	0.77 ± 0.13
	Brown Swiss cross	b±S.E.	0.56$ ± 0.01	1.02 ± 0.14	1.48# ± 0.07
	Holstein	b±S.E.	0.41# ± 0.09	0.77 ± 0.17	1.85# ± 0.08
	Variance ratios:				
	Between slopes		5.44**	2.76**	5.54**
	Between intercepts		----	----	----
Heifers	Hereford	b±S.E.	1.12 ± 0.60	0.50# ± 0.05	0.76 ± 0.05
	Shorthorn cross	b±S.E.	1.31# ± 0.05	0.78 ± 0.05	0.71 ± 0.12
	Variance ratios:				
	Between slopes		0.17	0.17	2.09
	Between intercepts		18.41**	3.12	26.50**

* Significant at ($P<0.05$).
** Significant at ($P<0.01$).
$ Significantly different from 1.0 ($P<0.05$).
# Significantly different from 1.0 ($P<0.01$).

intercepts in subcutaneous and body cavity depots are interpreted as early established groups differences in amount of fat in these depots between the two breed groups. Differences reflect time of onset of fattening rather than relative rate of fat deposition.

b) Influence of sex

Sexes did not differ consistently in the magnitude of growth coefficients for the fat depots (Table 26). HY bulls and steers differed significantly ($P<0.01$) in growth coefficients for both subcutaneous and intermuscular fat. Hereford heifers had a higher coefficient for body cavity fat than steers or bulls. No other growth coefficients were significantly different among sexes within breeds.

Where the intercepts could be tested they were significantly different ($P< 0.05$) between HY X HE bulls and steers for body cavity fat and between HL bulls and steers for subcutaneous fat. Sex differences in fat distribution in these groups is therefore related to time of onset of fattening rather than differing relative rates of deposition.

The conclusion that can be made from this section is that there is a considerable breed variation in bull and steer groups in the growth coefficients of all three components of fat. There was no such difference between the two breeds of heifers. The growth coefficients of fat in the subcutaneous fat were relatively higher in HE and low in dairy cattle and this trend was reverse in the body cavity fat. The other breed groups were intermediate in this respect. Sex influence was neither conspicuous nor did show any definite trend in these constants.

TABLE 26

Among sex group comparisons of growth coefficients of component fats in five breeds

Breed groups		Hereford			Variance ratios between		Hybrid		Variance ratios between		Hybrid X Hereford		Variance ratios between		Shorthorn cross			Variance ratios between		Holstein		Variance ratios between	
Sex		Bulls	Steers	Heifers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts	Bulls	Steers	Heifers	Slopes	Intercepts	Bulls	Steers	Slopes	Intercepts
Subcutaneous fat	b	1.08	1.34	1.12	0.98	0.14	1.05	1.30	19.74**	----	1.06	1.31	1.83	3.64	1.07	1.22	1.31	1.85	1.14	0.36	0.41	2.34	12.36**
Intermuscular fat	b	0.75	0.62	0.50	3.08	1.02	0.91	0.83	18.60**	----	0.99	0.79	0.92	1.60	0.98	0.87	0.78	1.35	0.53	0.32	0.77	1.77	4.30
Body cavity fat	b	0.56	0.63	0.76	7.06**	----	0.88	0.74	0.92	0.17	0.70	0.61	0.15	5.88*	0.97	0.77	0.71	0.93	1.22	3.54	1.85	2.08	3.93

* Significant at ($P<0.05$).
** Significant at ($P<0.01$).

SUMMARY AND CONCLUSIONS

The present research project was designed to investigate the influence of breed and sex on the growth patterns and distribution of muscle, bone and fat in 191 beef cattle consisting of 63 bulls, 106 steers and 22 heifers representing 6, 8 and 2 breed groups respectively. The total and proportion of muscle, bone, fat and muscle:bone ratios differed significantly ($P < 0.01$) among breed groups of bulls and steers indicating different patterns of tissue growth in various groups. The two breed groups of heifers were quite similar in their mean ages, liveweights, carcass and tissue weights reflecting a similarity in their type and growth characteristics.

Sex exerted a remarkable influence on the growth rate and developmental patterns of different tissues. Bulls grew faster compared with steers and steers compared with heifers. Similar was the trend in the rate of daily muscle gain. In contrast heifers were fattening faster compared with either bulls or steers. Heifers fattened at lighter liveweights than steers and steers at lighter weights than intact males. Bulls showed a higher growth impetus for muscle over steers and steers over heifers. Of the three major tissues bone appeared to be least affected by sex. Sex differences in the muscle:bone ratios were not consistent although bulls were favoured over steers or heifers. However, bulls were superior in muscle:fat ratio over steers and steers compared with heifers. This indicates that slaughter of animals of different sexes at a constant liveweight is not legitimate for comparable carcass composition. Similarity in the proportion of major tissues in the carcass could be brought about by shifting the slaughter weight in different sexes.

The relationships involving total muscle, muscle:bone and percentage fat was also studied to explore the feasibility of establishing a suitable index to determine the genetic merit of the carcass composition from divergent breed-groups and different sexes within a breed. Another objective of this approach was to test the influence of breed and sex on the adjusted mean estimated through the slopes.

Muscle plus bone was found to be the only legitimate variable for adjusting total muscle in the carcass from divergent breed groups of bulls, steers or heifers. Additionally, there was significant breed variations in the adjusted total muscle when the variation in total muscle plus bone was removed. This would indicate that selection for meatiness could be proposed on the basis of the test criterion. However, it may be quite difficult for all practical purposes. In all sex comparisons the slopes were found to be homogeneous in the relationships involving total muscle and muscle plus bone. However, there was no appreciable difference in the total muscle when the independent variable was held to a constant level. Nevertheless, bulls were superior (non-significantly) over steers and steers over heifers. This would indicate that sex comparisons should be made on a fat free basis to test the real genetic merit of the carcass because the inclusion of a highly variable component like fat will have a masking effect on the other tissues.

Among breed group variation in muscle:bone ratio was present when variation in muscle, fat, muscle plus bone or cold carcass weights were standardized. This would precisely indicate that groups of animals differing in carcass weight could be compared through muscle:bone ratio if the rate of change of this ratio against adjusted

carcass weight in a breed is estimated and adjusted for. Bulls were favoured in muscle:bone ratio over steers and steers over heifers in all comparisons except that in Hybrid X Hereford crossbreeds. This indicates a sex difference in the growth impetus for muscle growth in that order.

Percentage fat tended to increase in all breeds of bulls, steers or heifers when various tissue weights, except bone, increased. This was probably a reflection of the tendency of heavier animals to have been fatter and of fat deposition to have been rapid compared with other tissues. Bone or muscle plus bone was again found to be legitimate for adjusting percentage fat in the carcass. In all sex comparisons, at equal weights of the independent variables heifers had higher weights of fat than steers and steers were fatter than bulls. This indicated that heifers fattened relatively at lighter weights than steers and steers compared with heifers.

Muscle weight distribution showed significant breed variation in abdominal and neck & thoracic region. There was no appreciable difference in any other anatomical location indicating that selection for conformation or type did not change the muscle weight distribution in a desired direction. This further supports the hypothesis that breed differences in the proportion of lean meat in high priced regions of the carcass are minimal. Therefore emphasis in selection might best be placed on those traits which show greater variability among breeds, e.g. rate of gain, feed efficiency and carcass composition. Sex exerted a strong influence on the muscles of the proximal hind quarter and abdominal regions with heifers having higher proportions than steers and steers over entire males. This trend of sex influence was

reverse in the muscles of the neck and thorax. The rate of growth of muscles in different anatomical location relative to total muscles also showed similar trends of breed and sex influence as discussed above.

The larger breeds contained proportionately more bone in the axial part of the skeleton and also in the long bones of the limbs compared with the smaller breeds while the medium sized breeds were intermediate in position. This trend of breed influences was completely reversed in the bones of ribs. There was a considerable breed variation in the other sections of the skeletal system without showing any such consistency or trend in those parts. Sex also exerted influence on the distribution of bones. Bulls tended to contain proportionately more bones in all the sections of vertebral columns, ribs and sternum & rib cartilages over steers and steers over heifers. This trend was reversed in the long bones of limbs and in hip bones with heifers having greater proportion of bone compared with steers and steers compared with heifers. The growth coefficients further supported the trends of breed and sex influences on the bone weight distribution.

The fatty tissue distribution was strongly influenced by different breeds of bulls, steers or heifers. Beef breeds showed more subcutaneous fat and less body cavity fat compared with dairy cattle while the Shorthorn crosses, Hybrid and other beef crosses were intermediate in position. Ratios of the different fat component showed that dairy cattle fatten from inside out and beef cattle from outside in. So these data conclusively show that selection for type or conformation caused a shifting of fat without changing the lean tissue distribution.

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APPENDIX TABLE 1

Names of individual muscles comprising anatomical groups

Muscle No.	Names of Muscles	Names of Anatomical Muscle Groups	Codes Used To Indicate Anatomical Muscle Groups
1	M. cutaneus trunci	Abdominal region	4
2	M. tensor fasciae latae	Proximal pelvic limb	1
3	M. biceps femoris	Proximal pelvic limb	1
4	M. gluteus medius	Proximal pelvic limb	1
5	M. vastus lateralis	Proximal pelvic limb	1
6	M. glutaeus accessorius	Proximal pelvic limb	1
7	M. glutaeus profundus	Proximal pelvic limb	1
8	M. rectus femoris	Proximal pelvic limb	1
9	M. semitendinosus	Proximal pelvic limb	1
10	M. gracilis	Proximal pelvic limb	1
11	M. semimembranosus	Proximal pelvic limb	1
12	M. adductor femoris	Proximal pelvic limb	1
13	Mm. gastrocnemius et soleus	Distal pelvic limb	2
14	M. flexor digitorum superficialis	Distal pelvic limb	2
15	M. pectineus	Proximal pelvic limb	1
16	M. sartorius	Proximal pelvic limb	1
17	M. gemellus	Proximal pelvic limb	1
18	M. quadratus femoris	Proximal pelvic limb	1
19	Mm. obturator internus et externus	Proximal pelvic limb	1
20	M. vastus medialis	Proximal pelvic limb	1
21	M. vastus intermedius	Proximal pelvic limb	1
22	M. articularis genu	Proximal pelvic limb	1
23	Extensor group	Distal pelvic limb	2
24	M. peronaeus longus	Distal pelvic limb	2
25	M. extensor digiti quarti proprius (pedis)	Distal pelvic limb	2
26	M. tibialis anterior	Distal pelvic limb	2
27	M. tibialis posterior	Distal pelvic limb	2
28	M. popliteus	Distal pelvic limb	2
29	M. flexor digitorum longus	Distal pelvic limb	2
30	M. flexor hallucis longus	Distal pelvic limb	2
31	M. psoas minor	Surrounding spinal column	3
32	M. psoas major	Surrounding spinal column	3
33	M. quadratus lumborum	Surrounding spinal column	3
34	M. iliacus	Proximal pelvic limb	1
35	M. latissimus dorsi	Thorax to thoracic limb	7
36	M. trapezius thoracis	Thorax to thoracic limb	7

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Names of individual muscles comprising anatomical groups

Muscle No.	Names of Muscles	Names of Anatomical Muscle Groups	Codes Used To Indicate Anatomical Muscle Groups
37	M. serratus dorsalis caudalis	Abdominal region	4
38	M. iliocostalis	Surrounding spinal column	3
39	M. longissimus dorsi	Surrounding spinal column	3
40	M. spinalis dorsi	Surrounding spinal column	3
41	Mm. multifidi dorsi	Surrounding spinal column	3
42	M. obliquus externus abdominis	Abdominal region	4
43	M. retractor costae	Abdominal region	4
44	M. obliquus internus abdominis	Abdominal region	4
45	M. transversus abdominis	Abdominal region	4
46	M. rectus abdominis	Abdominal region	4
47	M. diaphragm	Scrap	10
48, 49	Mm. sacrococcygeus ventralis, lateralis et dorsalis	Scrap	10
50	Mm. intercostales externi et interni	Neck to thorax	9
51	M. sternocephalicus	Scrap	10
52	M. trapezius cervicalis	Neck to thoracic limb	8
53	M. deltoideus	Proximal thoracic limb	5
54	M. infraspinatus	Proximal thoracic limb	5
55	M. triceps brachii (caput laterale)	Proximal thoracic limb	5
56	M. teres minor	Proximal thoracic limb	5
57	M. triceps brachii (caput longum)	Proximal thoracic limb	5
58	M. tensor fasciae anti-brachii	Proximal thoracic limb	5
59	M. extensor carpii radialis	Distal thoracic limb	6
60	M. extensor digiti tertii proprius	Distal thoracic limb	6
61	M. extensor digitorum communis	Distal thoracic limb	6
62	M. extensor digiti quarti proprius	Distal thoracic limb	6
63	M. extensor carpi ulnaris	Distal thoracic limb	6
64	M. extensor carpi obliquus	Distal thoracic limb	6

APPENDIX TABLE 1

Names of individual muscles comprising anatomical groups

Muscle No.	Names of Muscles	Names of Anatomical Muscle Groups	Codes Used To Indicate Anatomical Muscle Groups
65	M. omotransversarius	Neck to thoracic limb	8
66	M. rhomboideus	Neck to thoracic limb	8
67	M. serratus ventralis cervicis	Neck to thoracic limb	8
68	M. serratus ventralis thoracis	Thorax to thoracic limb	7
69	M. pectoralis profundus	Thorax to thoracic limb	7
70	M. pectoralis superficialis	Thorax to thoracic limb	7
71	M. supraspinatus	Proximal thoracic limb	5
72	M. biceps brachii	Proximal thoracic limb	5
73	M. teres major	Proximal thoracic limb	5
74	M. coracobrachialis	Proximal thoracic limb	5
75	M. subscapularis	Proximal thoracic limb	5
76	M. brachialis	Proximal thoracic limb	5
77	M. brachiocephalicus	Proximal thoracic limb	5
78	M. triceps brachii (caput mediale)	Proximal thoracic limb	5
79	M. flexor carpii radialis	Distal thoracic limb	6
80	M. flexor carpii ulnaris	Distal thoracic limb	6
81	M. flexor digitorum sublimis	Distal thoracic limb	6
82	M. flexor digitorum profundus	Distal thoracic limb	6
83	M. anconaeus cranialis	Distal thoracic limb	6
84	M. serratus dorsalis cranialis	Neck to thorax	9
85	M. scalenus dorsalis	Neck to thorax	9
86	M. cervicohyoideus	Neck to thorax	9
87	M. longissimus cervicis	Surrounding spinal column	3
88	M. splenius	Neck to thorax	9
89	M. scalenus ventralis	Neck to thorax	9
90	M. longus capitis	Neck to thorax	9
91	M. intertransversarius longus	Neck to thorax	9
92	Mm. longissimus capitis et atlantis	Neck to thorax	9
93	Mm. intertransversarii cervicis	Neck to thorax	9
94	M. semispinalis capitis	Neck to thorax	9
95	M. rectus capitis dorsalis major	Neck to thorax	9
96	M. obliquus capitis caudalis	Neck to thorax	9

APPENDIX TABLE 1

Names of individual muscles comprising anatomical groups

Muscle No.	Names of Muscles	Names of Anatomical Muscle Groups	Codes Used To Indicate Anatomical Muscle Groups
97	M. rectus thoracis	Neck to thorax	9
98	M. transversus thoracis	Neck to thorax	9
99	M. longus colli	Neck to thorax	9
100	M. multifidi cervicis	Neck to thorax	9